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The Study of boundary layer control in a turbopump diffuser with fluid injection

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THE STUDY OF BOUNDARY LAYER CONTROL IN A TURBOPUMP DIFFUSER WITH FLUID INJECTION

by

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In memory of Carmen Garcia Pastor and Alvaro Lambas Ramon

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List of Symbols

AR	-	Area Ratio
B_t	-	Throat Blockage
b	-	Span
C_i	-	Coefficient Matrix
c	-	Speed of Sound
c_i , c_2	-	Empirical Constants
c_μ	-	Empirical Constant
c_p	-	Pressure Recovery Coefficient
$c_{p\,ideal}$	-	Ideal Pressure Recovery Coefficient
D_H	-	Hydraulic Diameter
Δt	-	Change in Time
E	-	Empirical Constant
F_i	-	Coefficient Matrix
f_i	-	Body Force Term
I	-	Turbulent Intensity
$I\mu$	-	Injection Coefficient
k	-	Turbulent Kinetic Energy
k^*	-	Dimensionless Turbulent Kinetic Energy
k_{ij}	-	Global Stiffness Matrix
L	-	Wall Length of Diffuser
L_j	-	Distance between shock origin in perfect fluid theory and injection slit

M	-	Coefficient Matrix
m	-	Mass Flow Rate
M_t	-	Throat Mach Number
N	-	Coefficient Matrix
p	-	Fluid Pressure
p_{tj}	-	Jets Stagnation Pressure
q_s	-	Heat Flux
R_{s_t}	-	Throat Reynolds Number
Re_d	-	Reynolds Number
R_i	-	Residual Errors
T	-	Temperature
t	-	Time
U	-	Global Displacement
u	-	Local Displacement
υ	–	Velocity
υ^*	–	Friction Velocity
υ^+	–	Dimensionless Velocity
V_{inlet}	–	Inlet Velocity
v_x, v_y	–	Blowing Velocity Components
v_t	–	Throat Velocity
V	–	Volume of Finite Element
W	–	Diffuser Width

x	–	Length
x^*	–	Dimensionless Length
y^+	–	Dimensionless Normal Distance From Diffuser Wall
θm	-	Momentum Thickness
2Θ	–	Divergence Angle of Diffuser
δ^*	–	Displacement Boundary Layer Thickness
ε	–	Turbulent Dissipation
ε^*	–	Dimensionless Turbulent Dissipation
φ	–	Column Vector of Interpolation Function
ψ	–	Column Vector of Interpolation Function
ϑ	–	Column Vector of Interpolation Function
η	–	Efficiency
η	–	Arbitrary Field Variable
$\bar{\eta}$	–	Time average of η
$\hat{\eta}$	–	Fluctuating Term of η
κ	–	Von Karman Constant
μ	–	Absolute Fluid Viscosity
μ_t	–	Eddy Viscosity
μ_0	–	Shear Viscosity
v	–	Kinematic Fluid Viscosity
θ	–	Incidence Angle
ρ	–	Fluid Density
$\rho \overline{u_i^{\prime}} \overline{u_j^{\prime}}$	–	Reynolds Stress

σ_ε - Turbulent Schmidt Number

σ_k - Turbulent Prandtl Number

τ_{tot} - Total Shear Stress (Laminar & Turbulent)

τ - Shear Stress at Diffuser Wall

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ABSTRACT.

Future Space Transfer Vehicles (STV) will be required to perform missions (orbital transfer, Lunar/Mars transfer and descents) for which deep engine throttling is needed. In order to do this the turbopumps that propel the Space Transfer Vehicles need to be able to operate at different flow rates. The current state of the art cryogenic fuel and oxidizer turbopump designs do not operate well at off-design flow rates mainly due to stall and flow separation in the diffuser section.

The purpose of this Thesis is to analyze the behavior of the fluid in the diffuser and the vaneless and vaned region of the MK49-F turbopump at different flow rates and to use fluid injection as a way to reduce the flow separation present in the vaned diffuser. To meet this objective a finite element based code, FIDAP, was used to build a three-dimensional model based on previous works done on the vaned diffuser. Previous works studied the behavior of the fluid in the vaned diffuser without taking into consideration the vaneless diffuser.

From the results obtained, it was observed that flow separation has occurred at the bottom plane of the vaned diffuser, when the flow rate was reduced to 60% of the design flow, and in the top plane of the vaneless region. These results are different from the ones obtained in previous works where the flow separation was found in the top plane of the vaned diffuser. This shows that with the addition of the vaneless section, the flow behavior changes significantly.

Fluid injection was applied at the bottom plane of the vaned diffuser through six different slits at 20% and 60% of the design flow. Various rates of fluid injection were tested for their effectiveness in suppressing or eliminating the flow separation. Results showed that at off-design flow conditions fluid injection is an effective way to eliminate separation.

CHAPTER 1. Introduction

1.1 Project Justification

The future space missions planned by NASA will use Space Transfer Vehicles to perform orbital transfer missions and Lunar/Mars transfer and descents. In order to do this properly, the vehicle must have a deep-engine throttling capability that can be obtained by designing a high performance liquid hydrogen (LH_2) turbopump which can efficiently output at different flow rates.

The current designs of high pressure, multistage turbopumps with radial vaned diffusers do not perform efficiently at off-design flow rates. The lower flow rates lead to poor diffuser performance, which can be observed by the flow separation and the diffuser stall, are due to the impeller discharge effects, increased boundary layer blockage and lack of turbulence intensity in the diffuser. This project investigates a means of increasing the diffuser performance at off-design flow rates without significantly altering the geometry of the diffuser.

The final objective of the Project at the Rochester Institute of Technology (R.I.T) is to develop methods to improve the performance of the MK49-F High Pressure LH_2 turbopump by improving the performance of the diffuser at off-design flow rates. In order to accomplish this goal, 3-D models of the vaned diffuser were developed using a finite element based code, FIDAP (Fluid Dynamics Analysis Package).

This Thesis presents the next step which is to develop a three-dimensional turbulent model consisting of the vaneless and vaned diffuser sections of the turbopump. These models will be used to gain a better understanding of the resulting flow patterns and to test the effectiveness of boundary layer control by means of fluid injection.

1.2 Project Objectives

A centrifugal turbopump is a radial flow turbomachine driven by a turbine. A typical stage of a turbopump includes the following functional elements:

1. An inducer section, within which the fluid is turned from an axial flow direction to a radial flow direction.

2. An impeller section, within which the fluid flows radially through the rotor.

3. A diffuser section, within which the fluid exiting the rotor is collected and directed to the pump exit.

These three functional elements do not necessarily correspond to structural elements of the pump. The functional inducer section consists of everything from the pump inlet to some radius within the structural rotor assembly where the flow of fluid is no longer has any axial component. The functional impeller section consists of that portion of the structural rotor assembly from the exit of the functional inducer section to the exit tip of the rotor blades. The functional diffuser section consists of everything from the exit tip of the rotor blades to the exit of the pump.

This last section of the pump, which is what this Thesis studies, can be divided into two separate regions. The first one would be the vaneless section that goes from the exit tip of the rotor blades until the fluid goes into the vaned diffuser and the second would be the vaned diffuser section , which is one of the basic components of the system and responsible for most of the conversion of the inlet dynamic pressure (kinetic energy) to static pressure rise. For subsonic flows, this is done by decelerating the fluid particles by providing a gradual and continuous increase of the cross-sectional area and try to recover as much of the inlet dynamic pressure during steady flow conditions. In addition, it is desired that the exiting flow is as steady as possible so it has a uniform velocity profile.

However, the diffuser performs in an adverse pressure gradient field which limits its efficiency and where the flow separation and stall occur due to the incompressible and viscous nature of the flow field.

Flow separation occurs when the fluid particles in a boundary layer are slowed down by wall friction. If the flow is sufficiently retarded, for example due to the presence of an adverse pressure gradient, the momentum of those particles will be reduced by both the wall shear and the pressure gradient. In terms of energy principles, the kinetic energy gained, at the expense of the potential energy, in the favorable pressure gradient region is depleted by viscous effects within the boundary layer. In the adverse pressure gradient region, the remaining kinetic energy is converted to potential energy but it is too small to surmount the pressure hill and the motion of the near wall fluid particles is eventually arrested. At separation, the reverse flow region next to the wall abruptly thickens, the normal component increases, and the boundary layer approximations are no longer valid. If the flow does not reattach itself to the diffuser wall it will dissipate into turbulent mixing and the diffusion process for providing pressure recovery will come to an end.

The goal of this work is to provide insight into the effectiveness of fluid injection as a boundary layer control method in suppressing or eliminating the diffuser stall that causes the poor performance at low flow rate conditions and also to demonstrate that this technique allows a pressure recovery that is substantially higher than in a diffuser without it. The work described here looks at a three dimensional computational model consisting of the vaneless and vaned diffuser sections of the turbopump under different flow conditions using the finite element code, FIDAP.

1.3 Project Description.

The MK 49-F High Pressure LH_2 Turbopump used by NASA can be seen in Figure 1. This turbopump was developed by the Rocketdyne Division of Rockwell International, which also developed a simplified version of it as a single stage Water Tester to run performance tests. The MK 49-F is a three stage, centrifugal, high pressure turbopump using liquid hydrogen as the working fluid. A high speed, high efficiency multistage centrifugal pump of this nature requires continuous passage diffuser crossovers. These diffuser crossovers act as channels for the fluid going from one stage to the next.

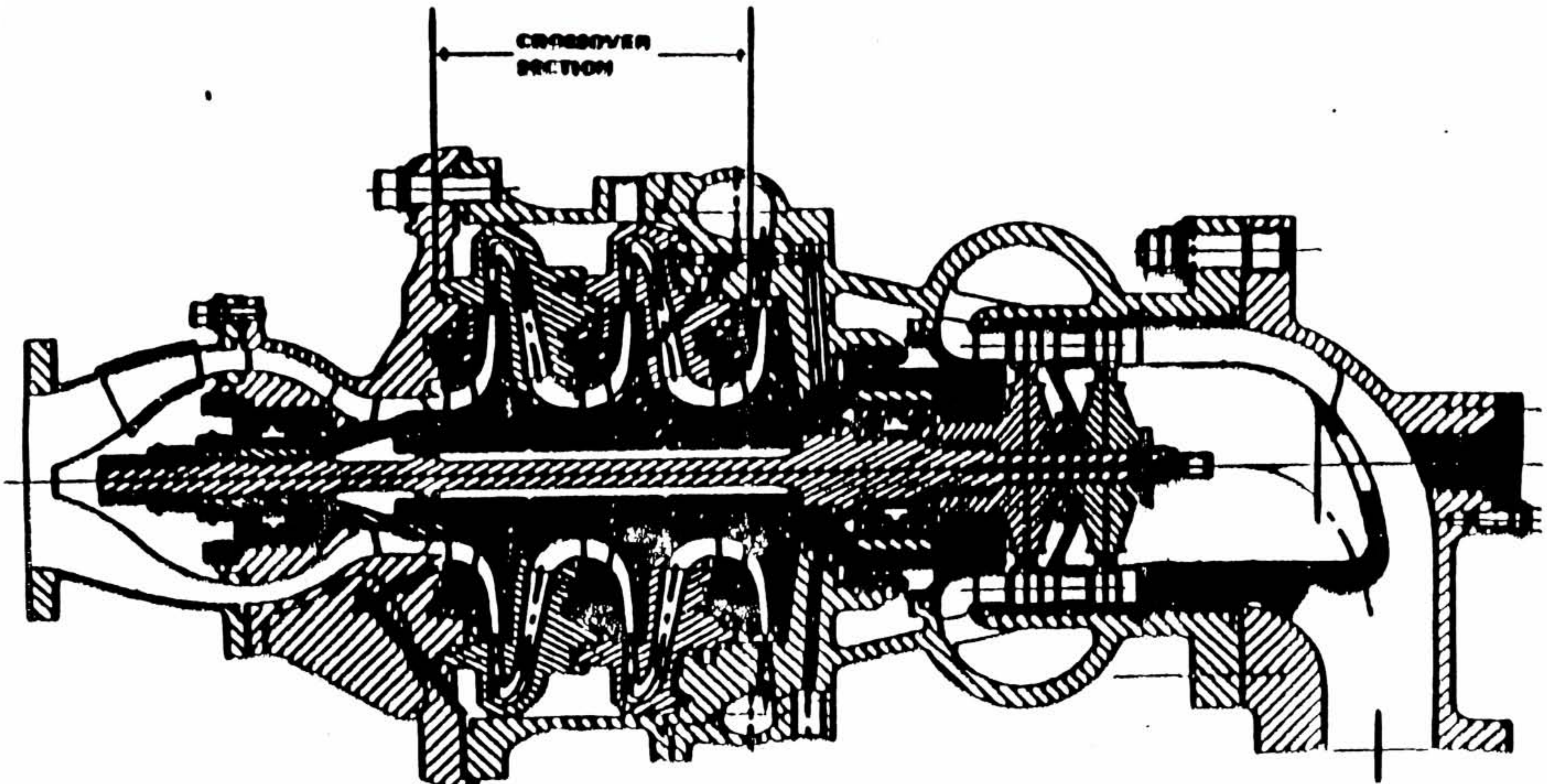
The pressure rise that can be achieved efficiently in a single stage is limited, depending on the type of machine. However, stages may be combined to produce multistage machines, virtually without limit on the pressure rise.

A characteristic of the MK 49-F is that it has 17 continuous crossovers passages between each impeller stage. These passages serve the purpose of conveying the pumped fluid from the exit of one impeller to the inlet of the next impeller and are of particular interest because this is where the recovery takes place. As it was mentioned before, Rocketdyne simulated the MK 49-F turbopump with a single stage Water Tester that was used to run performance tests. The Water Tester is shown in Figure 2, while Figure 3 shows the individual diffuser crossover section enlarged and dimensioned (Water Tester scaled up by a factor of 2.85).

Referring to Figure 3, the fluid path through an individual crossover passage can be described. The fluid leaves the blade tip at a high velocity and enters the vaned diffuser. The vanes guide the fluid from the impeller into the vaneless diffuser. Once it has entered the diffuser crossover section, the fluid flows into the upcomer which is a radial outflow diffuser where most of the recovery takes place. The fluid then flows through a turning channel, which is a transition area of constant cross-sectional area and then flows into the

TASK B.2: HIGH VELOCITY DIFFUSING CROSSOVER

MK49-F HIGH-PRESSURE LIQUID HYDROGEN TURBOPUMP



Rockwell International
Rocketdyne Division

Figure 1 - MK49-F High Pressure LH2 Turbopump.

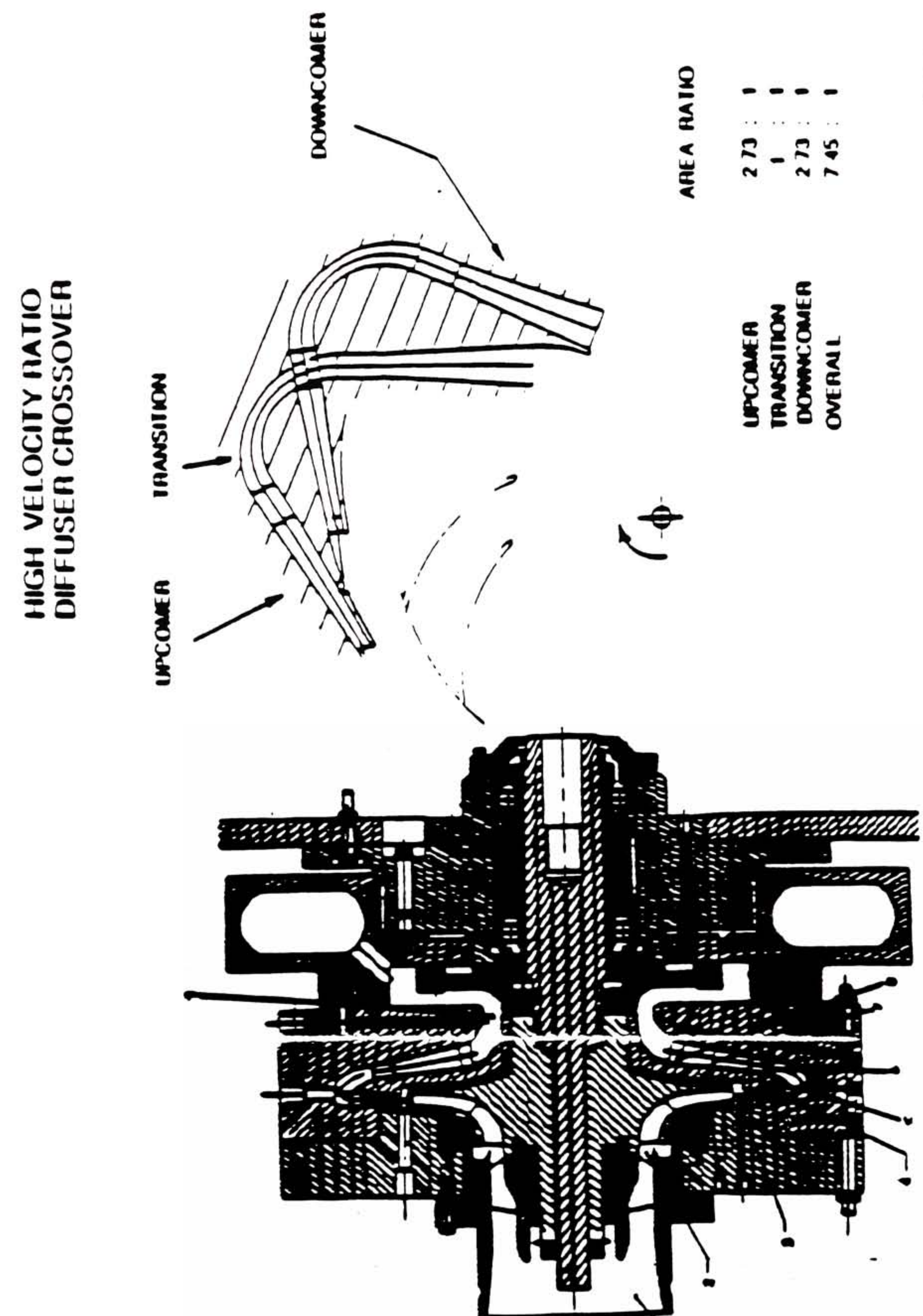


Figure 2 - High Velocity Ratio Diffuser Crossover (Rocketdyne Water Tester).

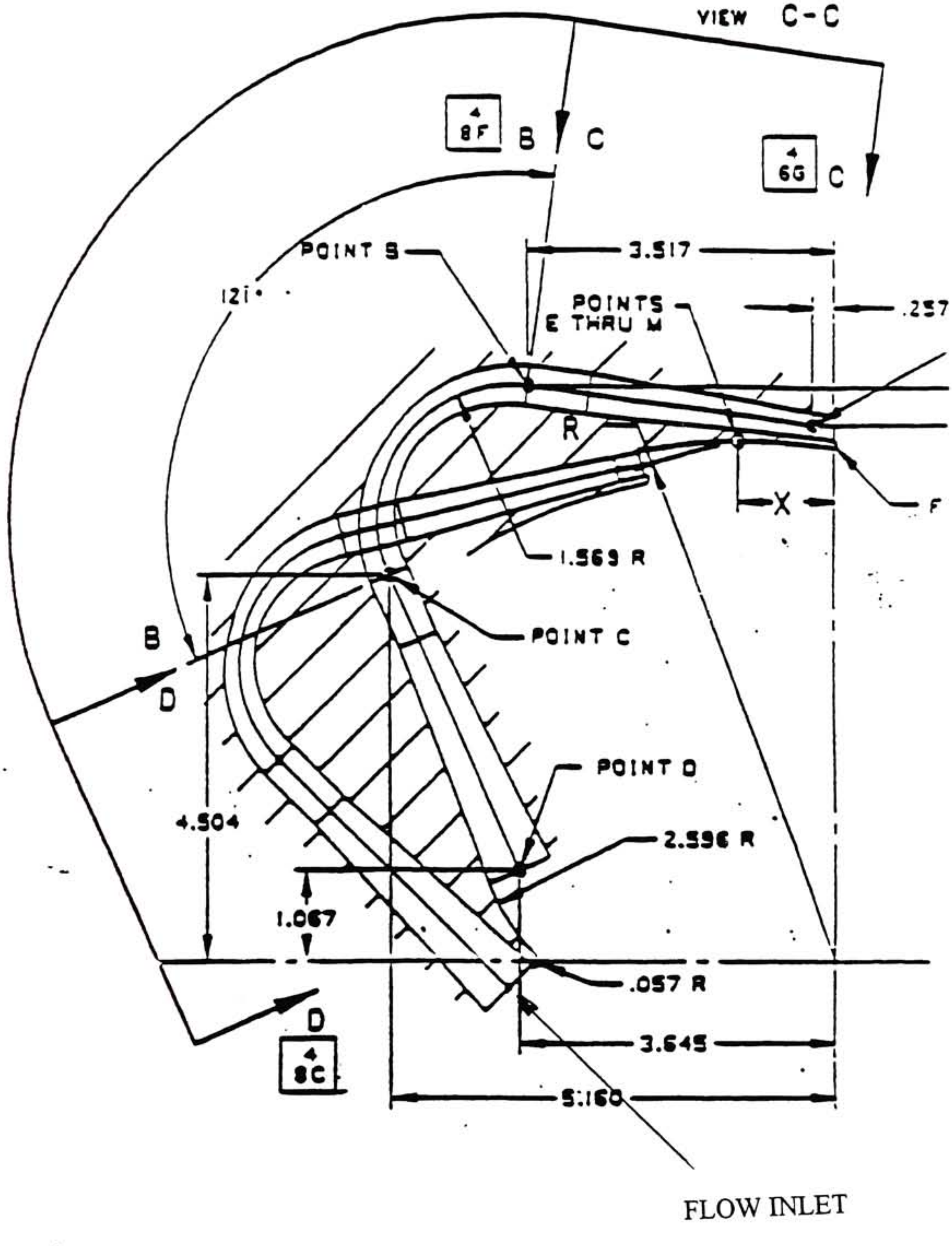


Figure 3 - Passage Definition.

downcomer which is a radial inflow diffuser, acting as a passage way to the next pump stage.

In this Thesis work, a three-dimensional model consisting of the vaneless and vaned diffuser sections of the turbopump was created using FIDAP.

CHAPTER 2. Principles of Turbulent Flow

2.1 Governing Equations

The Navier-Stokes equations describe fluid flow in either laminar or turbulent state. Taking into account the principles of conservation of mass, momentum and energy, these equations, when applied, will show us the behavior of the flow field within the turbopump vaneless and vaned section by describing the fluid flow at every point in the flow regime for all time.

$$u_{i,j} = 0 \qquad \text{(Eq. 1)}$$

$$\rho \left[\frac{\partial u_i}{\partial t} + u_j u_{i,j}\right] = -p_{,i} + \rho f_i + \rho g_i \left[1 - \beta \left(T - T_\beta\right)\right] + \left[\mu \left(u_{i,j} + u_{j,i}\right)\right]_j \qquad \text{(Eq. 2)}$$

$$\rho \; c_p \left[\frac{dT}{dt} + u_j \; T_{,j}\right] = \left(kT_{,j}\right)_{,j} + \mu \, \Phi + q_s \qquad \text{(Eq. 3)}$$

The type of flow that is used in this problem allows for some simplification because it is assumed that within the LH_2 turbopump diffuser, the flow can be described as turbulent, steady, incompressible, isothermal, and Newtonian in nature and therefore the conservation of energy equation will not be used and the equations for conservation of mass and momentum are reduced to:

$$u_{i,j} = 0 \qquad \text{(Eq. 4)}$$

$$\rho \; u_j \; u_{i,j} = -p_{,i} + \rho f_i + \left[\mu \left(u_{i,j} + u_{j,i}\right)\right]_j \qquad \text{(Eq. 5)}$$

where u is the fluid velocity with i, j = 1, 2, & 3 for a three-dimensional problem, p is the pressure, ρ is the density, and f represents the body forces.

2.2 Methodology of Analysis

Flows in turbopumps are highly turbulent. In turbulent flow situations, the fluid motion is highly random, unsteady, and three-dimensional and because of this the turbulent motion and mass-transfer phenomena associated with it are extremely difficult to describe and thus predict theoretically. It is believed that turbulent flows can be described with the use the of the time-dependent three-dimensional Navier-Stokes equations.

The best way to describe turbulent motion is by using time averaged quantities rather than instantaneous ones using the conservation laws for mass and momentum. These basic conservation laws are expressed by the equations 4 and 5. Osborne Reynolds was the first to suggest using a statistical approach where the equations are averaged over a time scale which is long compared with that of the turbulent motion to obtain the equations that describe the distribution of the mean velocity and pressure.

This approach separates the field variables (velocity, u_i and pressure, p) into mean and fluctuating quantities allowing for the use of mean values of the field variables ($\bar{u}_i$ and $\bar{p}$) in modeling the large scale flow characteristics. For an arbitrary field variable η, we can define its mean value as,

$$\bar{\eta} = \frac{1}{\Delta\tau} \int_{\tau}^{\tau+\Delta\tau} \eta \, d_{\tau} \qquad \text{(Eq. 6)}$$

where the averaging time Δt is long compared with the time scale of the turbulent motion.

The instantaneous variable η is then decomposed as,

$$\eta = \bar{\eta} + \eta' \qquad \text{(Eq. 7)}$$

where η' reflects the small scale fluctuations associated with turbulence. This decomposition is applied to the Navier-Stokes equations which are then integrated over the time interval (t, t + Δt) resulting in the following equations which govern the mean-flow quantities (the overbars indicating averaged values that will be dropped from this point forward) .

$$u_{i,j} = 0 \qquad \text{(Eq. 8)}$$

$$\rho\ u_j\ u_{i,j} = -p_{,i} + \rho\ f_i + \left[\mu\ (u_{i,j} + u_{j,i}) - \rho\ \overline{u_i'\ u_j'}\right]_j \qquad \text{(Eq. 9)}$$

Due to the non linearity of the Navier-Stokes equations, the averaging process introduces a correlation between fluctuating velocities $u_j u_i$, Multiplying this term by ρ gives the transport of momentum due to the turbulent motion. The term

$$\rho\ \overline{u_i' u_j'} = \frac{1}{\Delta t} \int_t^{t+\Delta t} \rho\ u_i'\ u_j'\ d\tau \qquad \text{(Eq. 10)}$$

describes the transport of x_i-momentum in the direction of x_j and acts as a stress on the fluid (Reynolds stress) and it also summarizes the effect of small scale eddy behavior on the large scale mean flow. To solve the Navier-Stokes equations and Eq. 10 requires a way of determining the turbulence correlation. This determination is the main roadblock in analyzing turbulent flows. A turbulence model which approximates this correlation along with the Navier-Stokes equations forms a closed set of equations which can be solved for the mean values of velocity and pressure.

The time averaging technique also provides a basis for some turbulent flow definitions. The intensity of the velocity fluctuations is given by their mean square value $\left(u_i'\right)^2$ Half of this value is defined as the turbulent kinetic energy.

$$k = \frac{1}{2}\,\overline{u_i^{/}\ u_i^{/}} \qquad \text{(Eq. 11)}$$

Another characteristic is the intensity of turbulence in the flow, which is defined as the root mean squared of the velocity fluctuations to the time mean velocity.

$$I = \frac{\left(\frac{1}{2}\,\overline{u_i^{/}\ u_i^{/}}\right)^{1/2}}{\overline{u_i}} = \frac{k^2}{36\overline{u_i}} \qquad \text{(Eq. 12)}$$

This dimensionless quantity is used as an indication of the turbulence level of the fluid at any point in the flow based on how much the velocity fluctuations deviate from the average flow. There are several other relationships that are important in understanding turbulent flows. The dimensionless velocity u^+, dimensionless normal distance from the wall y^+, the shear stress at the wall τ^*, and the friction velocity u^* are defined as follows:

$$u^+ = \frac{u}{u^*} \qquad \text{(Eq. 13)}$$

$$y^+ = \frac{\rho\, u^* y}{\mu} \qquad \text{(Eq. 14)}$$

$$\tau = \tau_{tot} \qquad \text{(Eq. 15)}$$

$$u^* = \sqrt{\frac{\tau^*}{\rho}}\ . \qquad \text{(Eq. 16)}$$

Based on Equations 13 through 16 and characteristics of turbulent flows, the flow regime can be divided into distinct regions. The region nearest the wall within a distance of $y^+=5$ is termed the viscous sublayer. Near the centerline of the flow at a distance greater than $y^+=30$ exists the fully developed turbulent region. In between these two regions it is found what is known as the buffer region. Figure 4 shows these regions in a graphical form [4]. The regions are defined by the different flow characteristics that are found within each region, which is helpful in discussing the complexities of turbulent flow.

2.3 Turbulent Flow Modeling Procedures

The eddy viscosity-diffusivity model often used to model the Reynolds stress is based on the assumption developed by Boussinesq [4] that the fluxes of momentum are proportional to the gradients of the mean flow field. Boussinesq introduced the proportionality parameter which is termed the eddy viscosity and is dependent upon the turbulence of the flow, which is a function of position. This relationship is defined as follows:

$$-\rho \overline{u_i' \ u_j'} = \mu_t \ (u_{i,j} + u_{j,i}) \qquad \text{(Eq. 17)}$$

This approximation allows Eq. 9 to be rewritten as Eq. 5 provided the total viscosity is identified as the sum of the shear and eddy viscosities.

$$\mu = \mu_0 + \mu_t \qquad \text{(Eq. 18)}$$

The eddy-viscosity concept transforms the problem of turbulence modeling to the determination of the distribution of μ_t.

Two turbulence models are commonly used, (a) the zero equation mixing length model and (b) the two equation k-ε model. Both are based on the Reynolds time averaged

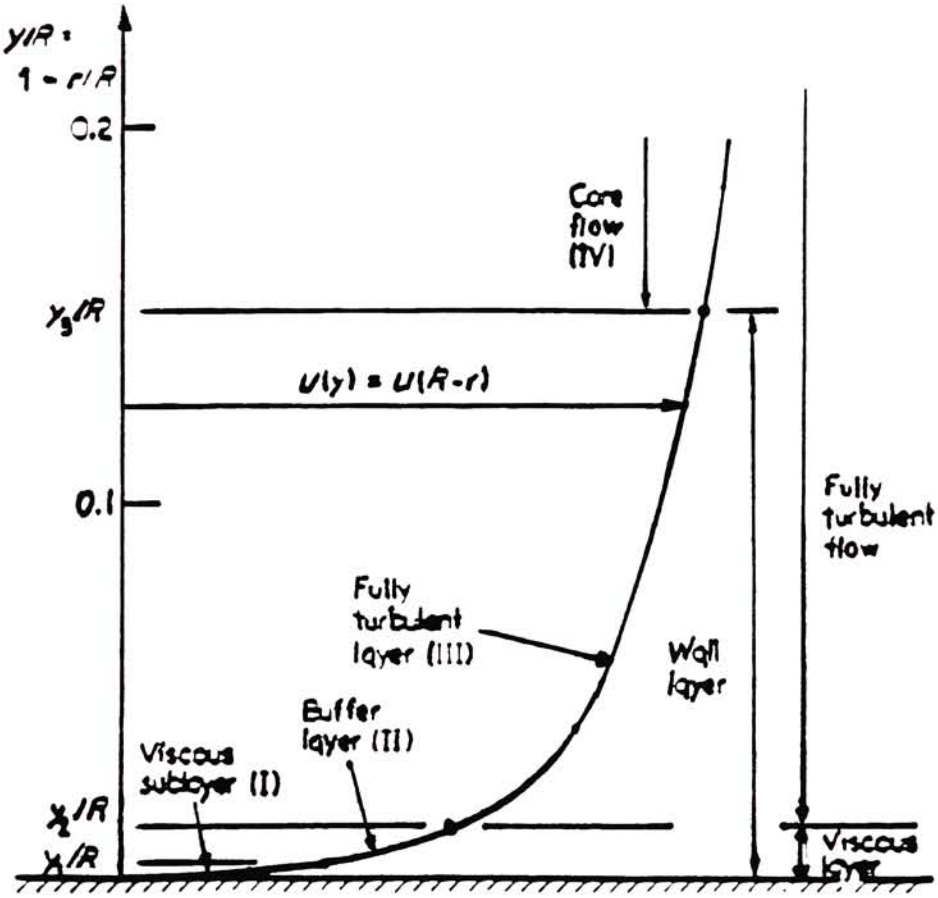


Figure 4 - Near Wall Model.

equations and use the eddy-viscosity concept, but the former model is not conducive to complex flows. Therefore, the two equation k-ε model was used because it is more effective in cases of flow separation and adverse pressure gradient flows.

The two equation k-ε model describes the turbulent kinetic energy associated with the small scale eddy behavior as shown in Equation 11, which suggests that velocity fluctuations can be characterized by the single parameter $k^{1/2}$, which in turn gives the approximation,

$$\mu_t \propto k^{1/2} \qquad \text{(Eq. 19)}$$

A transport equation for k can be obtained from the Navier-Stokes equations by algebraic manipulation. This transport equation involves ε, which is defined as,

$$\varepsilon = \nu\,\overline{u'_{i,j}\;u'_{i,j}} = \nu\,\frac{1}{\Delta t}\int_t^{t+\Delta t} u'_{i,j}\;u'_{i,j}\;d\tau \qquad \text{(Eq. 20)}$$

which represents the viscous dissipation of turbulent kinetic energy. A second transport equation for ε can also be derived from the Navier-Stokes equations. The transport equations of turbulent kinetic energy and viscous dissipation are;

$$\rho\;u_j\;k_{,j} = \left(\frac{\mu_t}{\sigma_k}k_{,j}\right)_{,j} + \mu_t\;\Phi - \rho\,\varepsilon \qquad \text{(Eq. 21)}$$

$$\rho\;u_j\;\varepsilon_{,j} = \left(\frac{\mu_t}{\sigma_t}\varepsilon_{,j}\right)_{,j} + c_1\frac{\varepsilon}{k}\mu_t\;\Phi - c_2\;\rho\;\frac{\varepsilon^{\,2}}{k} \qquad \text{(Eq. 22)}$$

where Φ is the viscous dissipation term, the eddy viscosity relationship,

$$\mu_t = \rho\, c_\mu \frac{k^2}{\varepsilon} \qquad \text{(Eq. 23)}$$

and the Navier-Stokes equations form a set of equations that will approximate the resulting turbulent flow in an internal passage. However, the equations are no longer exact and the results generated must be interpreted as approximate values. The previous equations contain several empirical constants which require definition. The empirical constants, c_μ, c_1 & c_2, are set at 0.09, 1.44, and 1.92 respectively for isothermal flows and the turbulent Prandtl and Schmidt numbers, σ_k & σ_ε , were determined to be 1.0 and 1.25 respectively for this flow situation [4].

The above results are for "high Reynolds number" flows and are useful in the fully turbulent region where the velocity profile is rather flat [4]. Due to the application of the no-slip condition at the diffuser walls, the flow characteristics are subject to very steep gradients near the wall. The above results will not be applicable over this low Reynolds number boundary layer. The Law-of-the-Wall model provides the link between the fully turbulent region and the no-slip, near wall region.

The Law-of-the-Wall model requires that the region under investigation be away from any stagnation, reattachment and separation points, with the flow parallel to the wall, no body forces present, and weak pressure gradients present. These assumptions may not hold for diffusers, but the model will be modified to relax these restrictions. A coordinate system is set up such that the first axis is tangent to the wall. The tangential momentum equation reduces to,

$$(\tau_{tot})_{,2} = 0 \qquad \text{(Eq. 24)}$$

where τ_{tot} is the sum of the laminar and turbulent shear stress,

$$\tau_{tot} = \mu\, u_{1,2} - \rho\, \overline{u_1' u_2'} \qquad \text{(Eq. 25)}$$

where $\mu\, u_{1,2}$ is the laminar shear stress and $\rho\, u'_1\, u'_2$ is the turbulent shear stress. In the near wall region, where $y^+ < 5$, the laminar shear stress is dominant. As the flow progresses through the buffer layer, where $5 < y^+ < 30$, turbulence is generated by an increase in turbulent shear stress and a decrease in laminar shear stress as can be seen in Figure 5. In the fully turbulent region, the turbulent shear stress is dominant. This analysis is in agreement with accepted boundary layer theory that indicates that the conventional fluid viscosity need only be accounted for within a very narrow region can be determined allowing for the development of the Law-of-the-Wall model.

Neglecting the turbulent shear stress in the viscous sublayer gives,

$$\tau_{tot} = \mu\, u_{1,2} \qquad \text{(Eq. 26)}$$

which by substitution and rearrangement leads to,

$$\frac{u}{u^*} = \frac{\rho\, u^*\, y}{\mu} \qquad \text{(Eq. 27)}$$

and by definition, this becomes the linear velocity profile

$$u^+ = y^+ \qquad \text{(Eq. 28)}$$

Beyond y^+ equal to 30, the viscosity of the fluid does not influence the total shear stress,

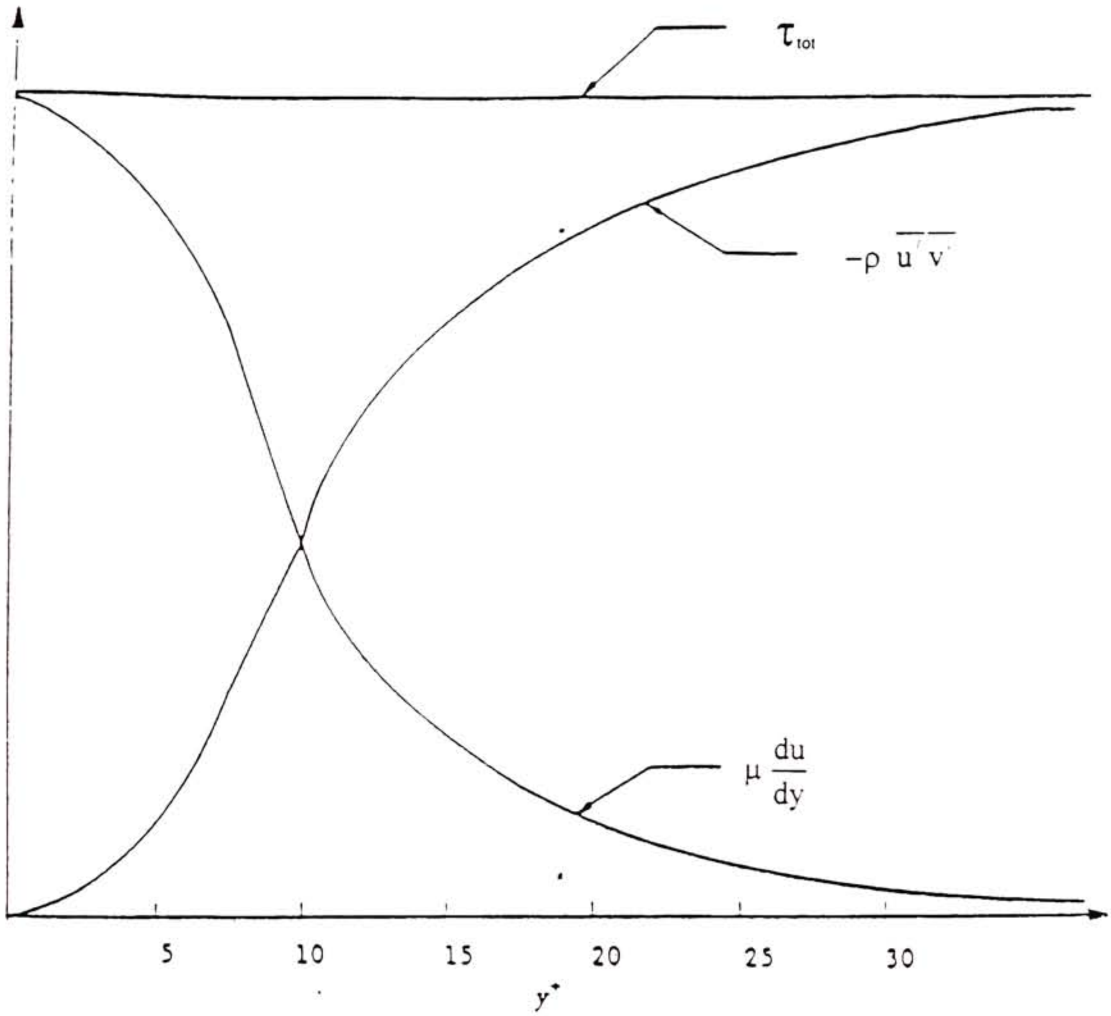


Figure 5 - Stress Profiles in the Near Wall Region.

so that,

$$\tau^{*} = -\rho\, \overline{u_1^{/} u_2^{/}} = \rho\, u^{*^2} \qquad \text{(Eq. 29)}$$

which leads to the classical logarithmic velocity profile,

$$\frac{u}{u^{*}} = \frac{1}{\kappa} \ln\left(\frac{E\rho\, u^{*} y}{\mu} \right) \qquad \text{(Eq. 30)}$$

where κ is the von Karman constant equal to 0.41 for this situation and E is an empirical constant equal to 9.0 [4].

Equations 28 and 30 are plotted in Figure 6 along with a typical velocity profile for the near wall region. From dimensional analysis, the equations for k and ε are given by,

$$k = c_{\mu}^{-0.5}\, u^{*^2} \qquad \text{(Eq. 31)}$$

$$\varepsilon = \frac{u^{*^3}}{ky} \qquad \text{(Eq. 32)}$$

The profiles for k and ε in the near wall region are shown in Figures 7 and 8 respectively [4]. As was stated in the earlier discussion, several restrictions were placed upon the Law-of-the-Wall model. Modifications to account for the flow separation and stall present in the diffuser will be employed with Equations 28 and 30-32 to approximate the near wall region.

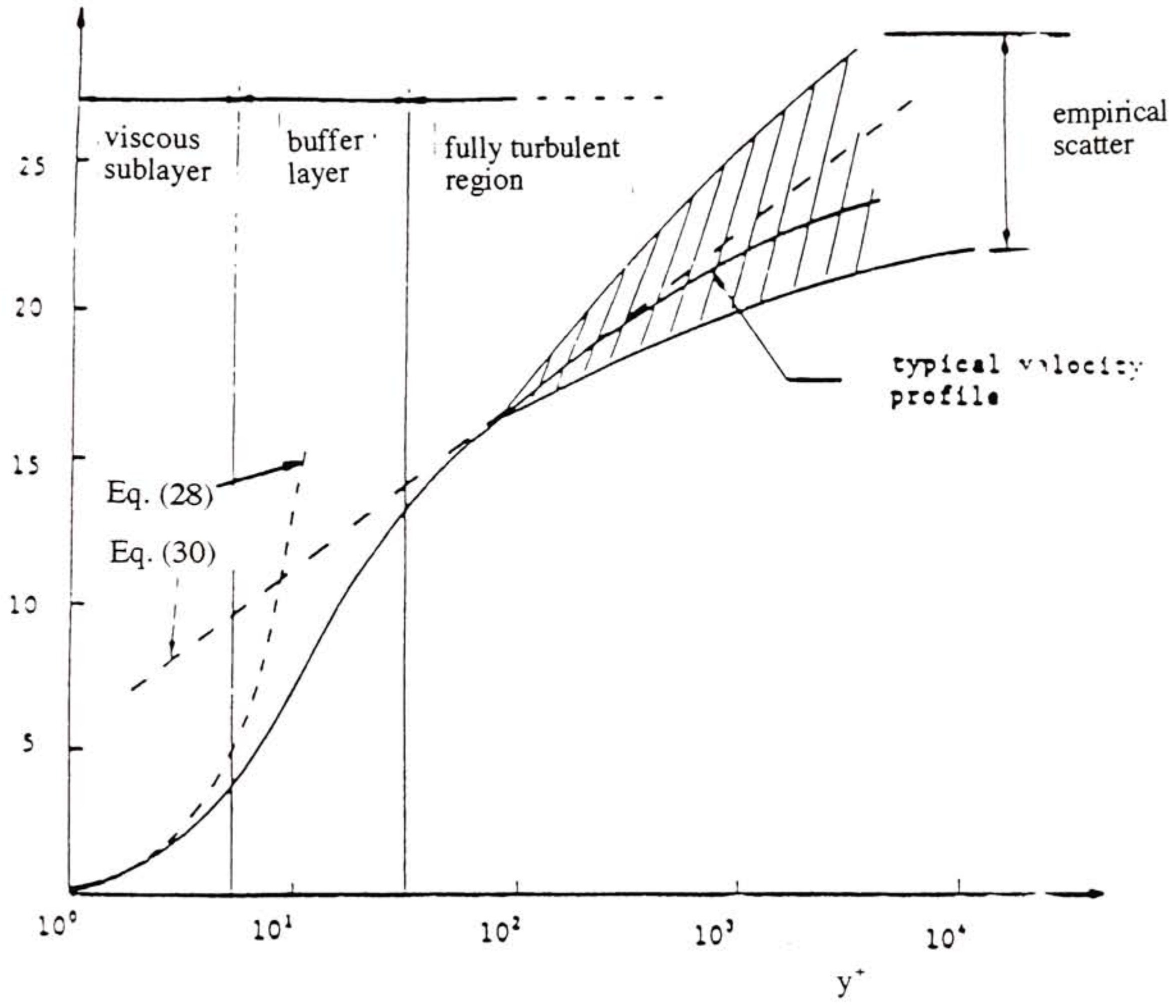


Figure 6 - Universal Velocity Profiles in the Near Wall Region.

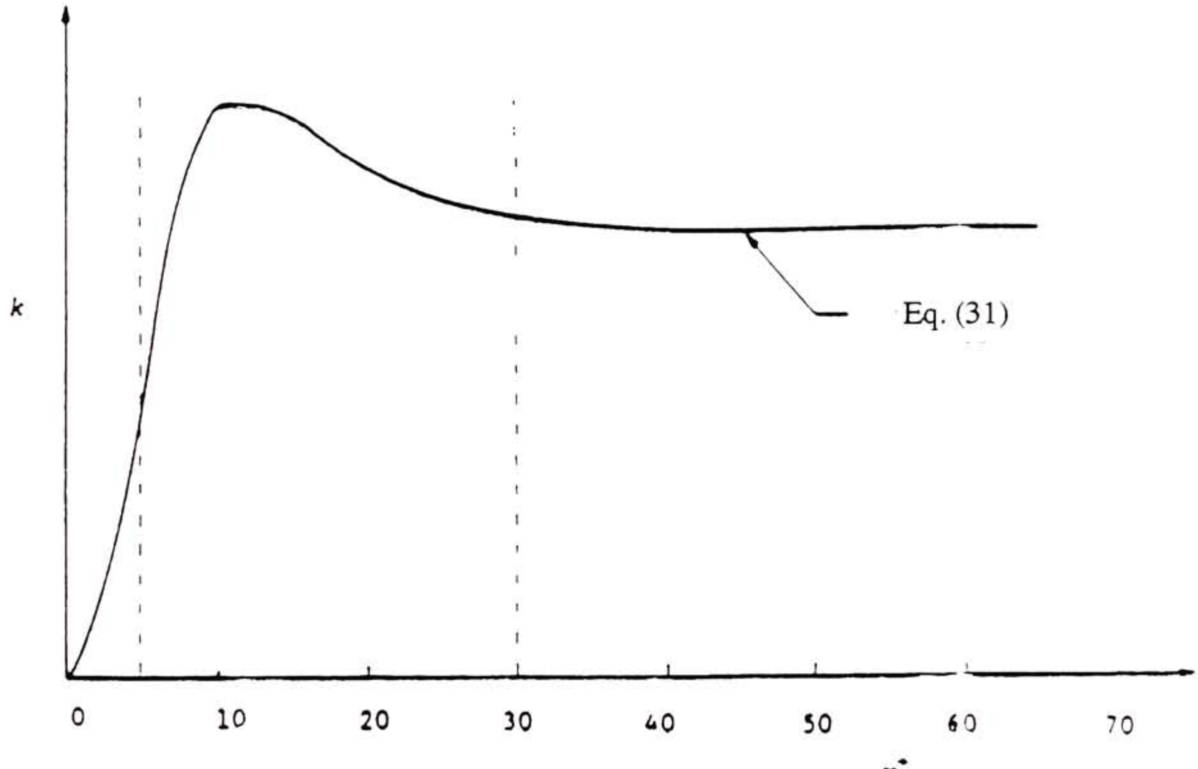


Figure 7 - Universal Kinetic Energy Profile in the Near Wall Region.

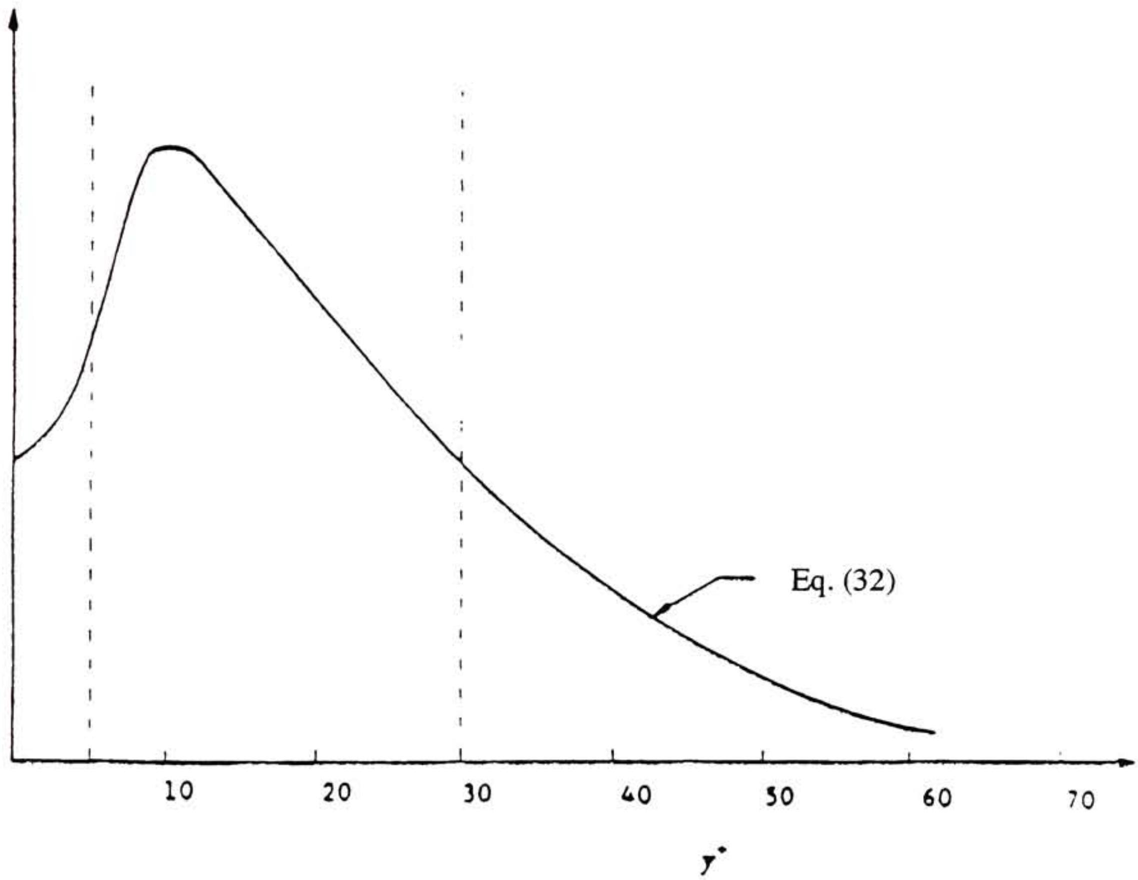


Figure 8 - Universal Viscous Dissipation Profile in the Near Wall Region.

CHAPTER 3. Principles of Diffusion

3.1 Description and Applications

A diffuser's purpose is to convert the inlet dynamic pressure of the fluid to a static pressure rise and this is why they are basic components in a turbomachine. For subsonic flow (M<1), this is accomplished by decelerating the fluid particles by the application of a gradual increase of the cross sectional flow area. In considering the effect of area variation on fluid properties in isentropic flow, we shall concern ourselves primarily with velocity and pressure. Using the equation,

$$\frac{dA}{A} = -\frac{dV}{V}[1 - M^2] \qquad \text{(Eq. 33)}$$

derived from the differential momentum equation for isentropic flow, it can be seen that for M<1 an area change causes a velocity change of opposite direction (positive dA means negative dV for M<1). A subsonic diffuser requires an increase of the passage area to cause a decrease in velocity. It is also important that the exiting flow is steady and has a uniform velocity profile for the next impeller stage.

There are several parameters used to describe a diffuser geometry [5]. These quantities are useful in analyzing the performance of the diffuser flow field. A simple diffuser is shown in Figure 9 [6]. The geometry of a diffuser is specified by the aspect ratio $\frac{b}{W_1}$, the divergence angle 2θ, the length-to-width ratio $\frac{L}{W_1}$, and the area ratio $\frac{W_2}{W_1}$ Losses in diffusers depend on a number of geometric and flow variables. Diffuser data most commonly is presented in terms of a pressure recovery coefficient, C_p, defined as the ratio of static pressure rise to inlet dynamic pressure:

$$C_p = \frac{p_2 - p_1}{\frac{1}{2}\rho\, v_t^2} \qquad \text{(Eq. 34)}$$

where p_2 is the outlet pressure, p_1 is the inlet pressure, and v_t is the mean velocity at the throat which is the straight channel prior to the vaneless diffuser.

The definition of C_p may be related to the head loss:

$$h_{l_m} = \frac{V_t^2}{2}\left[\left(1 - \frac{1}{(AR)^2}\right) - C_p\right] \qquad \text{(Eq. 35)}$$

For frictionless flow $h_{lm} = 0$, which gives us an ideal pressure recovery coefficient that is a function only of geometry,

$$C_{p_{ideal}} = 1 - \frac{1}{(AR)^2} \qquad \text{(Eq. 36)}$$

where AR is the area ratio, defined as

$$AR = \left(1 + \frac{N}{W_1}\tan\theta\right)^2 \qquad \text{(Eq. 37)}$$

The ratio of the actual pressure recovery coefficient to the ideal pressure recovery coefficient is the diffuser efficiency η.

$$\eta = \frac{C_p}{C_{p,ideal}} \qquad \text{(Eq. 38)}$$

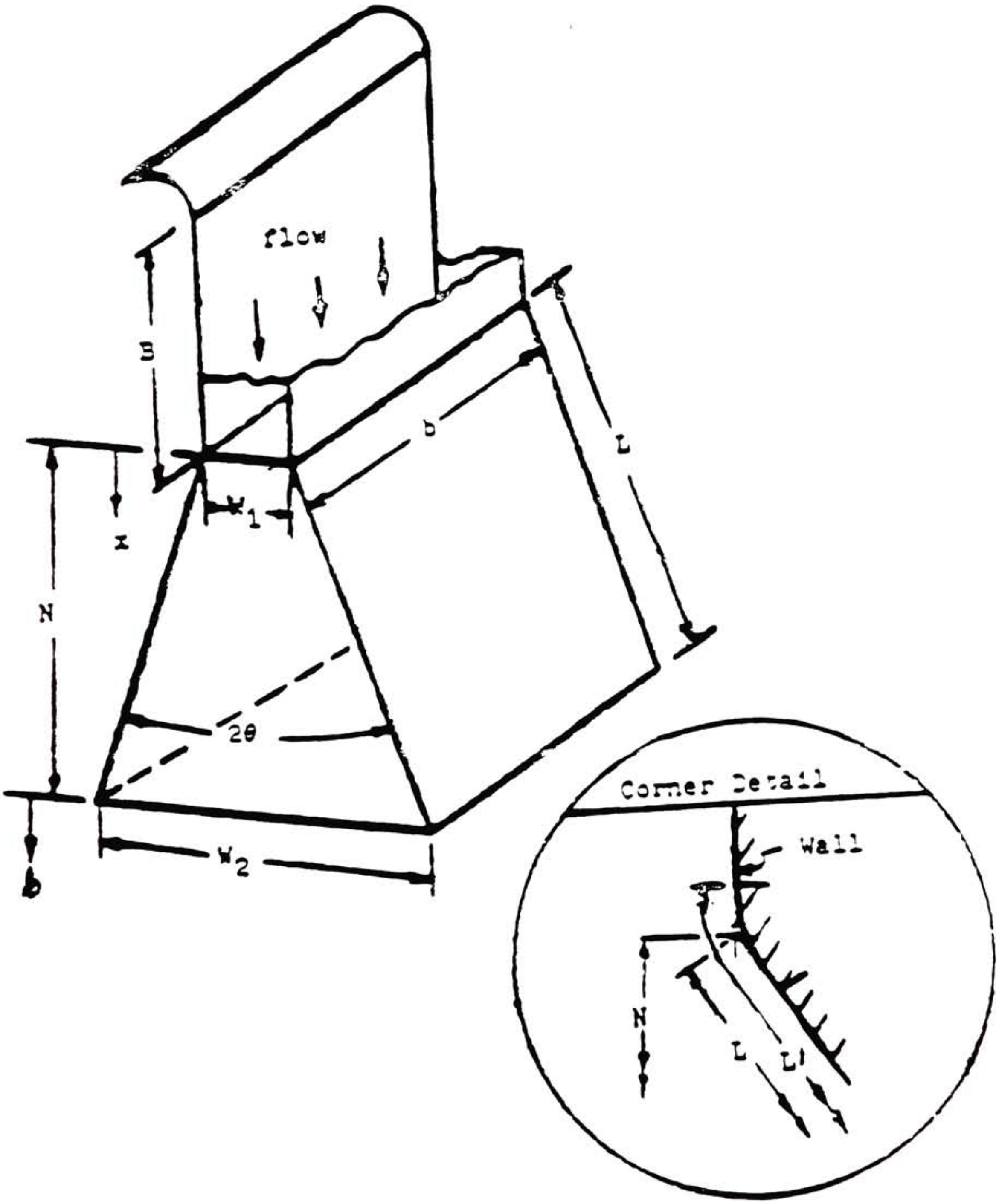


Figure 9 - Diffuser Geometry.

The diffuser flow characteristics for a subsonic and incompressible flow are given by the following parameters, the throat Reynolds number, R_{et}, and the throat blockage, B_t. Their definitions are given respectively as:

$$R_{et} = \frac{\rho \ v_t A}{\mu} \qquad \text{(Eq. 39)}$$

$$B_t = \frac{2\delta^*}{W} \qquad \text{(Eq. 40)}$$

where, W is the width of the throat and δ^* is the displacement boundary layer thickness calculated from the velocity profile.

$$\delta^* = \int_0^{\delta} \left(1 - \frac{u}{v_t}\right) dy \qquad \text{(Eq. 41)}$$

3.2 Diffuser Stall

Diffuser stall is a concept described by Prandtl's boundary layer theory [7]. In order to encounter diffuser stall a different phenomenom called boundary layer separation must first occur. Prandtl predicted, for a flow regime considered to be two-dimensional and steady, that a point of separation will occur in an adverse pressure gradient region $\left(\frac{\partial p}{\partial x}\right) > 0$, when the velocity gradient at the wall is zero, $\left(\frac{du}{dy}\right)_{y=0} = 0$ This implies that the shear stress at the wall is zero, $\tau = \mu \left(\frac{du}{dy}\right)_{y=0} = 0$

Figure 10 shows Prandtl's boundary layer concept for flow over an airfoil. It shows the effect on the velocity profile of frictional drag leading to the transition to stall and flow reversal.

The biggest difficulty of designing and employing diffusers is that the maximum pressure recovery and peak efficiency of most diffusers occurs when the adverse pressure gradient is greatest or near the so called stall line. This can be seen in Figure 13 that shows the pressure recovery as a function of area ratio for a constant aspect ratio. There are four major regions of stall defined as the no appreciable stall area, large transitory stall area, fully developed two--dimensional stall area and the jet flow area. Small diverging angles and area ratios characterize the area of no appreciable stall with the flow steady and symmetric with no visible disturbances. However, on the microscopic level, there is an appearance of very small stall bubbles continually regenerated and destroyed on the diverging walls. The formation of large stall regions near the diffuser throat causing large fluctuations in the pressure field characterizes the large transitory stall region. A large stationary stall bubble that grows from the diffuser throat along the wall characterizes two-dimensional stall. This creates a thick turbulent blockage area at the diffuser exit. The formation of stall regions on both diffuser walls, with a continuing steady flow along the centerline, characterizes the jet flow region.

Transitory stall in diffusers is a phenomenon of internal flow that is unsteady and very difficult to predict. In these unsteady flows , the maximum pressure recovery at constant diffuser length-to-width ratio, $\frac{L}{W_1}$, is achieved as transitory stall starts to develop [8]. Transitory stall was first recognized as a result of flow visualization experiments. The most useful contributions to this topic were made by Reneau, et al [10], who developed the pressure recovery chart (Figure 13), and by Fox and Kline [9], who performed diffuser flow regime studies (Figure 14). The pressure recovery chart shows how peak pressure recovery occurs right at the onset of the large transitory stall region.

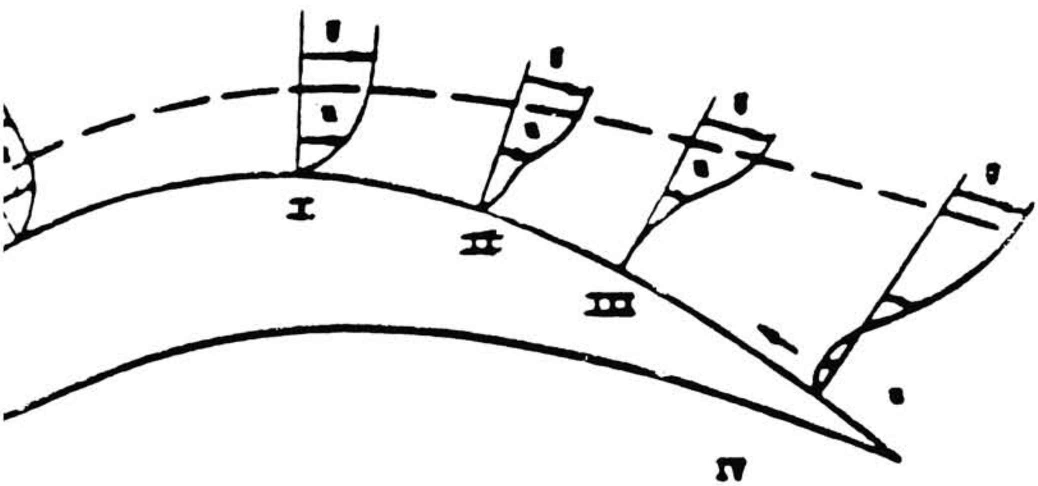


Figure 10 - Prandtl's Boundary Layer Concept.

The Flow Regime Chart developed by Fox and Kline is useful in predicting stall for different diffuser geometries. The chart bases its findings on the diffuser's geometry characterized by $\frac{N}{W_1}$ and 2θ.

The MK49-F turbopump diffuser's geometry is located itself on the Flow Regime Chart in the no appreciable stall region near the line a-a of Figure12. However, this chart is useful for predicting stall in diffusers at the design flow rates with no incidence angle effects. The incidence angles introduced by the flow entering the diffuser from the impeller blade tip effects the MK49-F diffuser as it throttles through various off-design flow rates.

It is important to note that diffusers with distorted inlet velocity profiles exhibit stall behavior quite different from that found in diffusers with uniform inlet velocity profiles, such as the development of a centerline pocket stall if the inlet velocity flow is severely distorted.

The development of the turbulent boundary layer has a significant impact on the diffuser performance. If the turbulent boundary layer is thick creating a large throat blockage, separation will occur near the inlet of the diverging section. The fluid particles decelerate near the wall region under the effect of an increasing pressure gradient and reduced transverse momentum transfer. As the fluid progresses through the diffuser, excessive blockage occurs reducing the diffuser efficiency. In turbopumps operating at off-design flow rates, this lack of turbulence intensity and increased frictional drag creates the environment for flow separation.

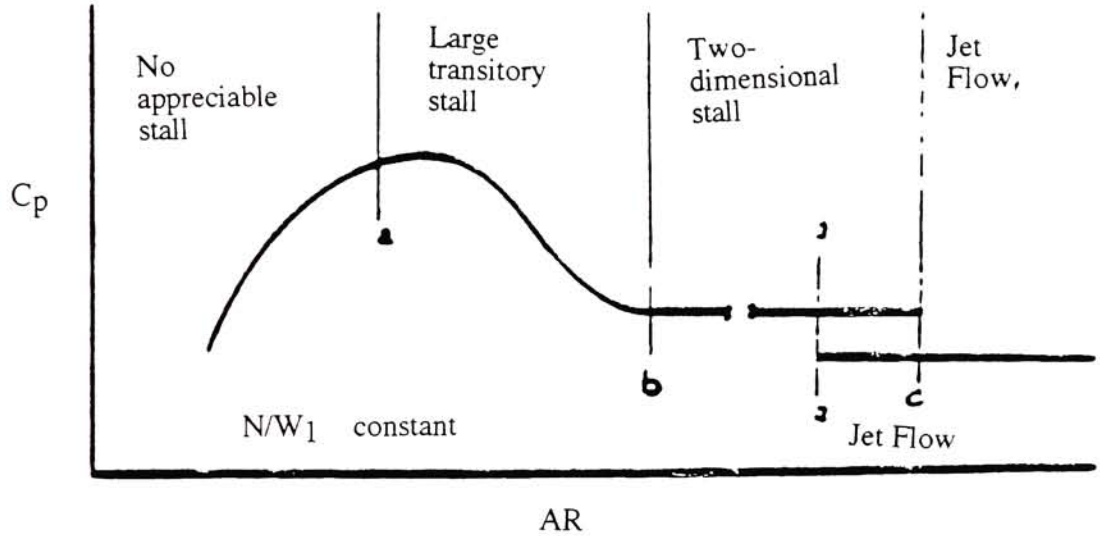


Figure 11 - Diffuser Pressure Recovery Chart.

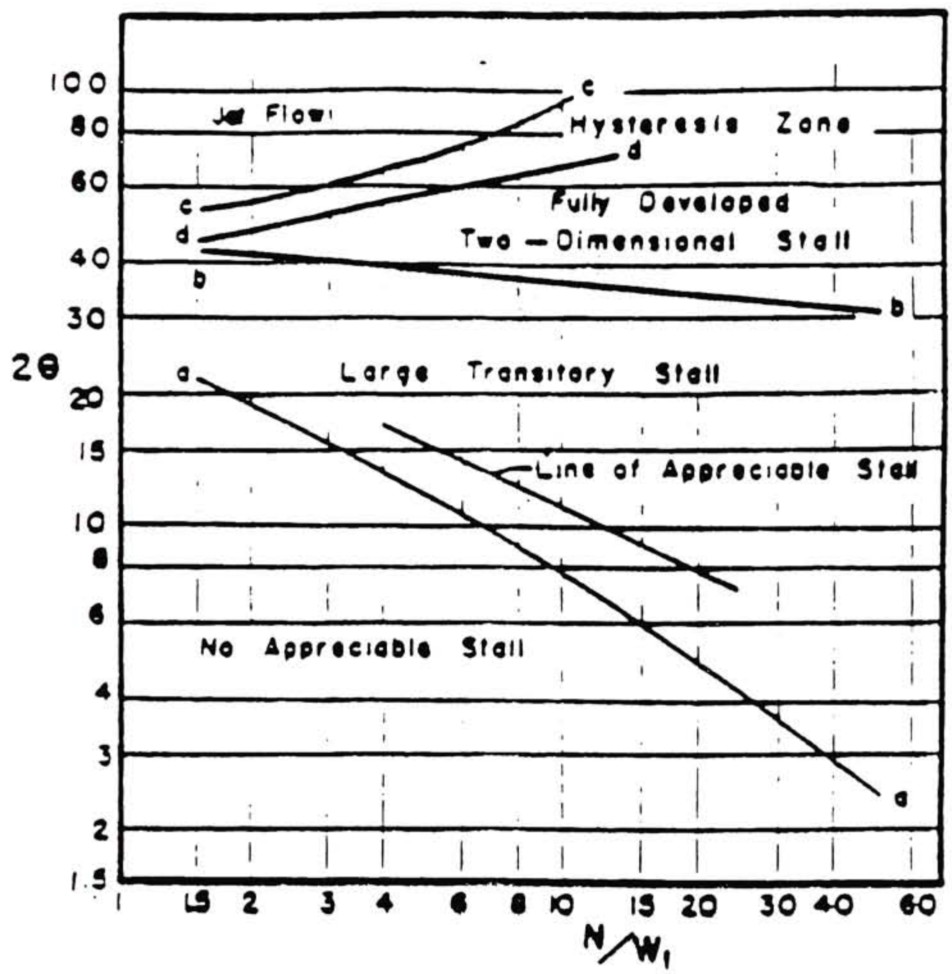


Figure 12 - Diffuser Flow Regime Chart.

CHAPTER 4. Boundary Layer Control by Fluid Injection.

4.1 Flow Separation.

Great advances have been made in establishing a firm analytical foundation for steady, two-dimensional separation. On the other hand, theoretical or numerical analysis of three-dimensional or unsteady separation is less developed. The breakthrough in unsteady separation research was achieved by Moore, Rott, and Sears [22] during the 1950's. Prior to their work it was believed that steady and unsteady separations have the same characteristics; namely, the point of vanishing wall shear, the termination of the boundary layer, and the beginning of the wake or bubble of separated fluid. Rott in 1956 analyzing the unsteady flow in the vicinity of a stagnation point, noted that the point of vanishing wall shear does not coincide with the point of boundary layer detachment. In 1958, while investigating a steady flow over a moving wall, he arrived to the conclusion that for a slow moving wall, separation occurs when, at some point in the boundary layer, the profile velocity and shear simultaneously vanish.

4.2 Control of Boundary Layer Separation by Fluid Injection.

The term boundary layer control includes any mechanism or process through which the boundary layer is caused to behave differently than it normally would, were the flow developing naturally along a smooth straight surface.

Separation control is of immense importance to the performance of turbomachines, diffusers, air and water vehicles, etc. On the other hand, in some instances it may be beneficial to provoke separation.

4.2.1 Active and Passive Fluid Injection.

Near-wall momentum addition is the usual approach of choice for control of residual flow separation remaining after mitigation of the causative pressure field or off-design conditions. Common to all the different control methods is the supply of additional energy to the near-wall fluid particles which are being retarded in the boundary layer. The additional longitudinal momentum is provided either from an external source or through local redirection into the wall region. Passive techniques do not require auxiliary power, but do have an associated drag penalty, and include intentional tripping of transition from laminar to turbulent flow upstream of what would be a laminar separation point, boundary layer fences to prevent separation at the tips of swept-back wings, placing an array of vortex generators on the body to raise the turbulence level and enhance the momentum and energy in the neighborhood of the wall, rippled trailing edge, streamwise corrugations, stepped afterbodies to form a system of captive vortices in the base of a blunt body, or using a screen to divert the flow and increase the velocity gradient at the wall.

Active methods to postpone separation require energy expenditure. Obviously, the energy gained by the effective control of separation must exceed that required by the device. A fluid may be injected parallel to the wall to augment the shear-layer momentum or normal to the wall to enhance the mixing rate. Either a blower is used or the pressure differential that exists on the aerodynamic body itself is utilized to discharge the fluid into the retarded region on the boundary layer. The latter method is found in nature in the thumb pinion of a pheasant, the split-tail of a falcon, or the layered wings feathers of some birds.

In man-made devices, passive blowing through leading-edge slits and trailing edge flaps is commonly used on aircraft wings. Although in this case direct energy expenditure is not required, the blowing intensity is limited by the pressure differentials obtainable on the body itself. Nevertheless, the effect of passive blowing on lift and drag could be dramatic. This is shown in the Figure 13 for the NACA 23012 airfoil section with no flap, with a single trailing-edge flap and with a double-slotted flap. Compared to the clean (no flap) case, with a single trailing-edge flap is used the maximum lift is increased by about 175% while the section drag at C_{lmax} is increased by more than 180%. The corresponding numbers when a double-slotted flap is used are respectively, 230 and 500%.

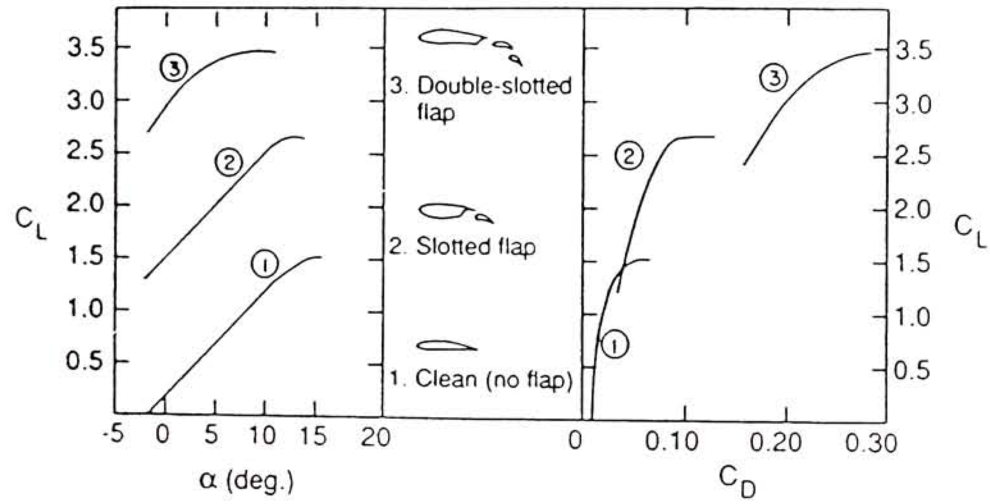
Direct tangential injection, wall jets, was and still is the preferred and straightfoward flow separation control technique since removal and ejection of low stagnation pressure fluid (fluid suction) can be difficult in some instances since this technique requires a complex arrangement of several independent bleed chambers that are not always possible to install.

As it was mentioned before, the basic principle of fluid injection, consists in bringing momentum to the flow in order to increase its ability to overcome, with minimum damage, an adverse pressure gradient.

The efficiency of fluid injection depends on several parameters, the most determining being the momentum i_j of the injected fluid and the distance L_j between the injection slits and the separation point. The maximum allowable distance L_j can be estimated by first computing δ_j, the physical thickness of the boundary layer, with a convenient boundary layer method and then applying a separation criterion.

In Figure 14 it is shown that, for a given value of i_j, the most appropiate distance L_j results from a compromise between two tendencies:

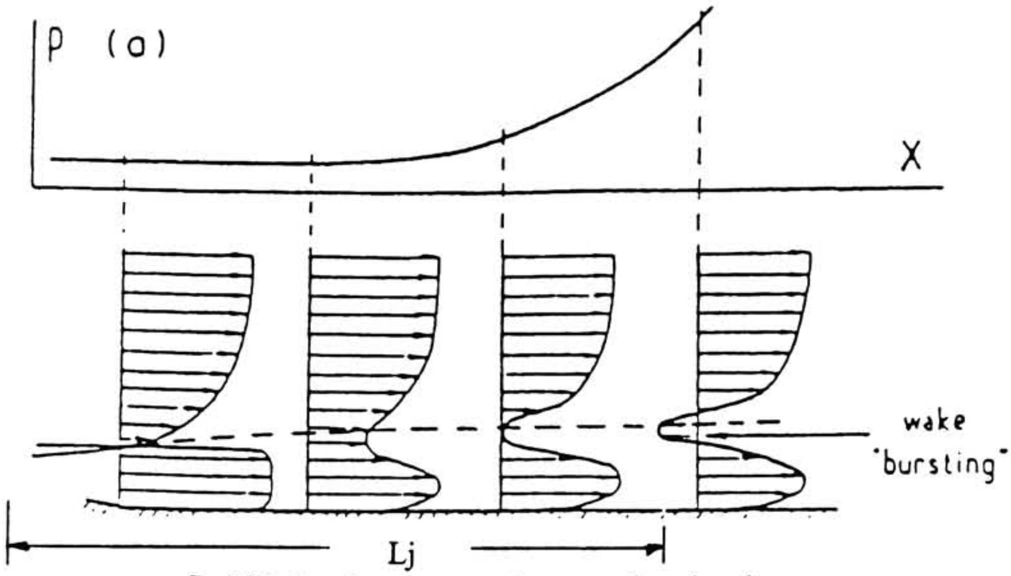
(1) L_j must be long enough to allow the mixing process by which momentum is transferred from the jet to the boundary layer in sufficient time to be really effective. If not, the adverse pressure gradient will drive back the insufficiently accelerated flow which creates a pocket of 'separated' flow within the fluid in the region where its velocity



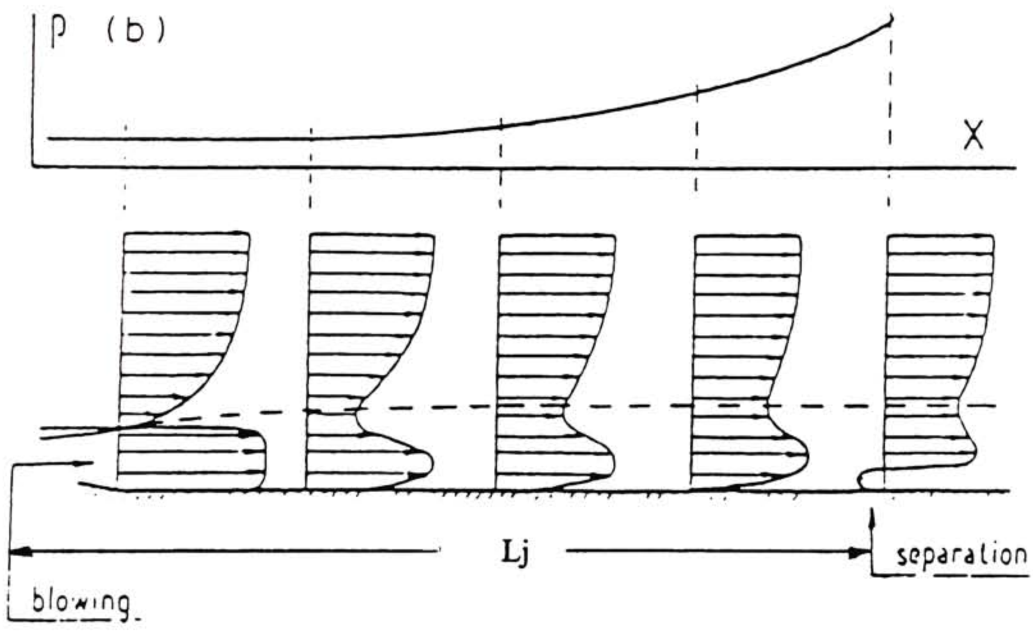
a. Lift curves.

b. Lift-drag polars.

Figure 13 - NACA 23012.



a - fluid injection is too close to the shock.



b - fluid injection is too far from the shock.

Figure 14 - Effect of Fluid Injection on Boundary Layer.

goes through a minimum (Fig 14-a) Such phenomenon is accompanied by a dramatic increase in the turbulence level which can be the cause of instabilities and loss of efficiency.

(2) The new boundary layer which builds up between the wall and the jet has a thickness δ_j increasing with L_j. Thus if the distance L_j is too long, δ_j will reach a value such that the pressure gradient (whose action increases in proportion with δ_j) will be in a position to separate the boundary layer (Fig. 14-b). Moreover, the jet maximum velocity decreases when L_j increases, which tends to worsen the process.

The injected momentum is most often characterized by the coefficient:

$$I_\mu = \frac{\dot{m}(u_j - u_{eo})}{\rho_{eo}\, u_{eo}^2\, \theta\, b}, \text{ (b = span, } \theta \text{ = momentum thickness)} \quad \text{(Eq. 42)}$$

Thus I_μ represents the ratio between the momentum excess in the injected fluid (relative to the local speed u_{eo} in the upstream flow) to the momentum deficit in the upstream boundary layer. The subscript e, designates the conditions at the boundary layer outer edge and the subscript o, designates conditions at the interaction origin.

The experiments used to verify this information found that the control system becomes inoperative for $M_0 = 2$. Indeed at this Mach number, the required injection mass flow is such that (for unchanged orifice size) the jets stagnation pressure p_{tj} is so high that the obstacle effect due to the jets expansion separates the boundary layer. One must be aware of this possible negative consequence of fluid injection, as it can be seen in Figure 14. In fact, by improving the injection system, interactions could be controlled up to M_o = 1.96 [23, 24]. In these experiments, it was also found that, at identical values of the mass flow $\dot{m}$, the injection of hot air did not appreciably improve the system's performance.

This finding is not expected since with hot injected fluid, the I_μ can be considerably increased (by more than 350% for a temperature ratio of 2). Hence, the investigators concluded that the coefficient defined with the injected momentum $i_j = \dot{m} u_j$ is the only one that makes sense physically speaking

In the diffuser studied, the flow separates along the lower wall of the diffuser due to the pronounced inlet incidence angles. As a result, fluid injection was applied at the bottom of the diffuser in an attempt to counteract the incidence angle effects and to energize the boundary layer. Several injection angles were studied in order to determine their effect on the boundary layer. The best results were obtained when the fluid was injected at a 35 degree angle from the diffuser centerline at each of the six slits.

The outflow of fluid across the six slits was uniform. The slits were positioned along the wall of the diffuser from the shroud side to the hub side (Figure 15). The slits were positioned near the diffuser inlet in order to more efficiently add momentum to the decelerating particles, as was suggested by the previous work of Wissinger [3] and Yoshida [2]. The slits are 2mm. in width and are placed 1.25 cm. apart. Several fluid injection rates were tested in order to investigate their effect on the boundary layer control. The injection rates studied were 3%, 5%, 10% and 15% of the total mass flow rate.

CHAPTER 5. FINITE ELEMENT METHOD

5.1 General Concepts

The flow field at any point in the domain of interest can be defined using the Navier-Stokes and transport equations of turbulent kinetic energy and viscous dissipation. The nonlinearities present in these equations each having an infinite number of degrees of freedom are solved using the Finite Element Method (FEM). This technique breakes down the region of interest into small geometric regions called finite elements and replaces the partial differential equations which govern the entire region with ordinary differential equations or algebraic equations within these regions. All of these regions are linked together via common boundary conditions and solved as a large system of equations using matrix algebra. The basic conversion procedure that FEA (Finite Element Analysis) is as follows: (1) Discretization of the domain, (2) Derivation of the element equations, (3) Assembly of global equations, (4) Imposition of boundary conditions, and (5) Solution of assembled equation.

An Eulerian approach is used to describe the fluid motion; elements are assumed to be fixed in space. Within each element, the dependent variables (u_i, p, T, k, and ε) are interpolated by functions of compatible order, in terms of values to be determined at a set of nodal points. For purposes of developing the equations for these nodal points unknowns, an individual element may be separated from the assembled system (discretization). The dependent variables are approximated by,

$$u_i (x,t) = \varphi^T U_i (t) \qquad \text{(Eq. 44)}$$

$$p(x,t) = \psi^T P(t) \qquad \text{(Eq. 45)}$$

$$T(x,t) = \vartheta^T T(t) \qquad \text{(Eq. 46)}$$

$$k(x,t) = \varphi^T K \qquad \text{(Eq. 47)}$$

$$\varepsilon(x,t) = \varphi^T E \qquad \text{(Eq. 48)}$$

where U_i, P, T, K, and E are column vectors of element nodal point unknowns and φ, ψ, and ϑ are column vectors of the interpolation functions. Substituing these approximations into the Navier-Stokes equations and the transport equations for kinetic energy and viscous dissipation yields a set of equations:

$$f_1(\varphi, \psi, \vartheta, U_i, P, T) = R_1 \quad \text{Momentum} \qquad \text{(Eq. 49)}$$

$$f_2(\varphi, U_i) = R_2 \quad \text{Incompressibility} \qquad \text{(Eq. 50)}$$

$$f_3(\varphi, \vartheta, U_i, T) = R_3 \quad \text{Energy} \qquad \text{(Eq. 51)}$$

$$f_4(\varphi, \psi, \vartheta, U_i, T, k, \varepsilon) = R_4 \quad \text{Transport - k} \qquad \text{(Eq. 52)}$$

$$f_5(\varphi, \psi, \vartheta, U_i, T, k, \varepsilon) = R_5 \quad \text{Transport - } \varepsilon \qquad \text{(Eq. 53)}$$

where R_1, R_2, R_3, R_4 and R_5 are the residuals or errors resulting from the approximations above.

The Galerkin form of the Method of Weighted Residuals seeks to reduce these errors to zero, in a weighted sense, by making the residuals orthogonal to the interpolation functions of each element. These orthogonality conditions are expressed by,

$$(f_1, \varphi) = (R_1, \varphi) = 0 \qquad \text{(Eq. 54)}$$

$$(f_2, \psi) = (R_2, \psi) = 0 \qquad \text{(Eq. 55)}$$

$$(f_3, \vartheta) = (R_3, \varphi) = 0 \qquad \text{(Eq.56)}$$

$$(f_4, \varphi) = (R_4, \varphi) = 0 \qquad \text{(Eq. 57)}$$

$$(f_5, \varphi) = (R_5, \varphi) = 0 \qquad \text{(Eq. 58)}$$

where (a,b) denotes the inner product, defined by,

$$(a,b) = \int_v a\, b\, dV \qquad \text{(Eq. 59)}$$

V being the volume of the element.

The results of these computations can be expressed by the following finite system of nonlinear ordinary differential equations:

$$\begin{bmatrix} M & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & M & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & M & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & N & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & M & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & M \end{bmatrix} \begin{Bmatrix} \dot{U}_1 \\ \dot{U}_2 \\ \dot{U}_3 \\ \dot{T} \\ \dot{P} \\ \dot{K} \\ \dot{E} \end{Bmatrix} + \begin{bmatrix} k_{11} & k_{12} & k_{13} & k_{14} & -C_1 & 0 & 0 \\ k_{21} & k_{22} & k_{23} & k_{24} & -C_2 & 0 & 0 \\ k_{31} & k_{32} & k_{33} & k_{34} & -C_3 & 0 & 0 \\ 0 & 0 & 0 & k_{44} & 0 & 0 & 0 \\ -C_1^T & -C_2^T & -C_3^T & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & k_{66} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & k_{77} \end{bmatrix} \begin{Bmatrix} U_1 \\ U_2 \\ U_3 \\ T \\ P \\ K \\ E \end{Bmatrix} = \begin{Bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ 0 \\ F_6 \\ F_7 \end{Bmatrix}$$

The submatrices M, N, C_i, k_{ij} and F_i are defined by:

$$M = \int_v \rho \ \varphi \ \varphi^T \ dV \qquad \text{(Eq. 60)}$$

$$N = \int_v \rho \ \vartheta \ \vartheta^T \ dV \qquad \text{(Eq. 61)}$$

$$C_i = \int_v \frac{\partial \varphi}{\partial \chi_i} \psi^T \ dV \qquad \text{(Eq. 62)}$$

$$k_{ii} = \int_v \mu \frac{\partial \varphi \quad \partial \varphi^T}{\partial \chi_i^2} \qquad \text{(Eq. 63)}$$

$$k_{ij} = \int_v \mu \frac{\partial \varphi}{\partial \chi_i} \frac{\partial \varphi^T}{\partial \chi_i} dV \qquad \text{(Eq. 64)}$$

$$F_i = \int_s \overline{t_i} \ \varphi \ dS + \int_v \rho \ f_i \ \varphi \ dV + \int_v \rho \ g_i \ \beta \ T_0 \ \varphi \ dV \qquad \text{(Eq. 65)}$$

5.2 FIDAP.

The FIDAP fluid dynamics analysis package is a general purpose computer program that uses a finite element method to simulate many classes of fluid flows. The solution method used in FIDAP is based on the finite element method (FEM), a technique which, while joining widespread use in structural problems, has a relatively short history in computational fluid dynamics. In FEM the flow region is subdivided into a number of small regions, called finite elements. The partial differential equations of fluid mechanics covering the flow region as a whole are replaced by ordinary differential equations in each element. The system of these equations is then solved by sophisticated numerical techniques to determine the velocities, pressures, temperatures, species concentrations and other unknowns throughout the region.

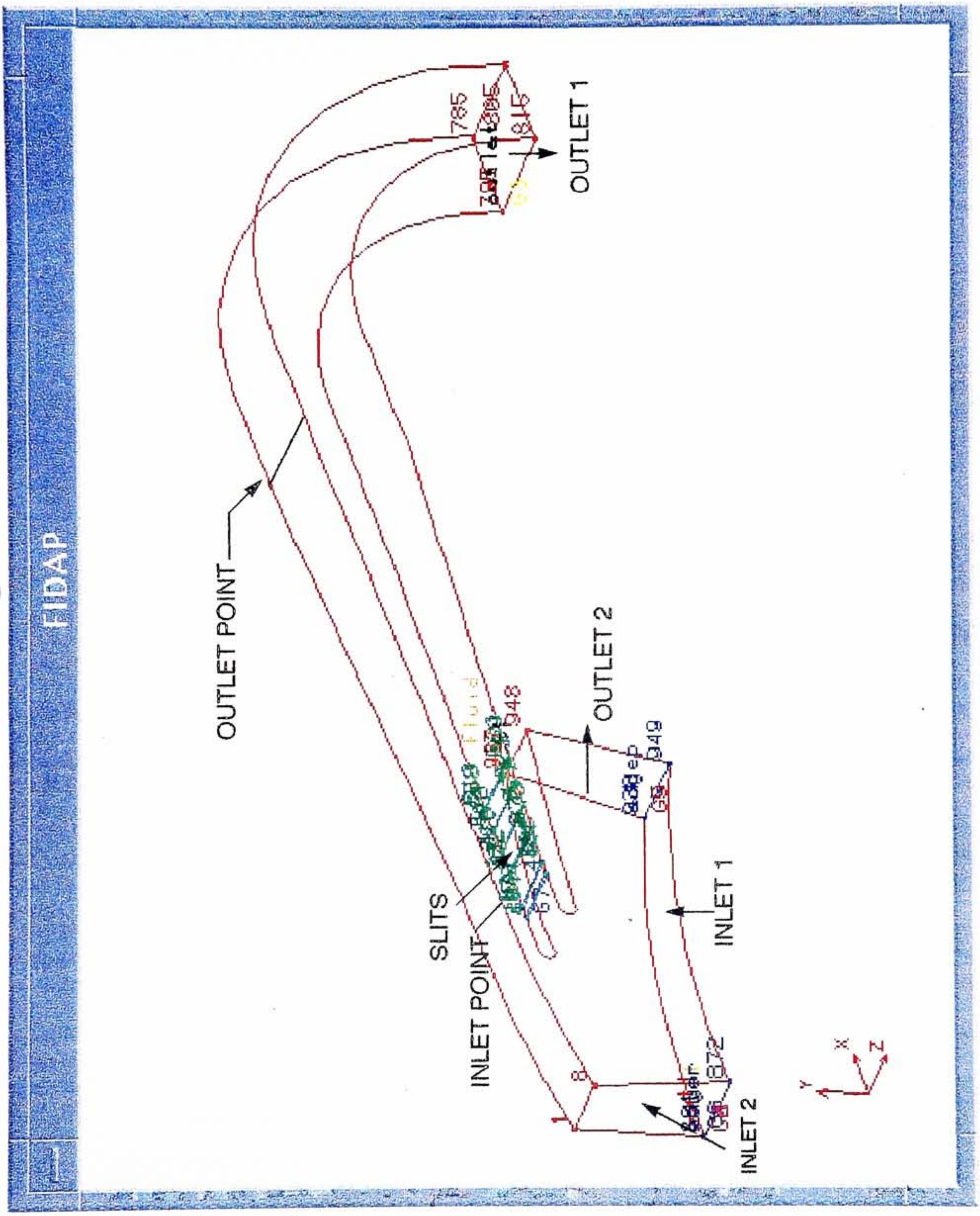


Figure 15 - Model's Geometry.

CHAPTER 6. Fidap Diffuser Model.

6.1 Three-Dimensional Diffuser Model.

The model that was created is identical to the other 16 that can be found in the turbopump and the results can be applied to any of the other diffusers. The model maintains geometrical similarity with the actual MK49-F turbopump diffuser and its conditions are equivalent to the flow conditions in the MK49-F turbopump.

The entrance region was composed of two different inlet areas as it can be seen in Figure 15. The first one is periodic with respect to the outlet, meaning that all the fluid that goes through the outlet is equal to the fluid coming in through the inlet. There is one other inlet located at the tip of the blade. The x and y components of the velocity from the blade tip going into the vaneless section were calculated using the velocity triangles at the impeller exit.

The boundary layer control method using fluid injection was tested, with six slits as shown in Figure 15. The fluid injection slits were located on the bottom of the diffuser, since this was the plane where the largest separation occurred, due to the fluid conditions at the diffuser inlet, and were extended from the shroud to the hub side with the shorter side in the direction of the flow. The amount of fluid injected through these slits was determined by the imposed boundary conditions. The fluid being injected is the same one going through the diffuser, liquid hydrogen.

6.2 Mesh.

The mesh is one of the most important parameters that should be taken into account when working with FIDAP.

The mesh density is variable in this problem. There are regions where the mesh is denser. This was done in order to get more detailed information on what is happening in specific regions where the fluid's properties are changing more rapidly and also where separation is expected. These areas are near the diffuser's top and bottom planes, all along the diffuser. The mesh was made coarser in region of lesser interest and well behaved responses. These areas are the turning channel, the diffuser's centerline and the vaneless and vaned region. Another factor that was taken into consideration was the reproducibility of the results since it is our desire to be able to compare these results with the ones that Yoshida [2] and Wissinger [3] obtained. The mesh density used in those cases is not identical to the one used in this case but it follows the same basic parameters. The main reasons for this difference were the reduced computer space and the additional elements that had to be created on the vaneless and vaned region. This last factor did not have to be taken into consideration in the previous works mentioned above.

6.3 Nondimensionalization.

The different variables used to solve this problem were nondimensionalized with respect to characteristic values. For the length and the velocity, the characteristic values chosen were the diffuser's inlet width and the inlet fluid velocity respectively. To specify a nondimensionalized model, the FIDAP input file must set the fluid density to unity and the viscosity as the inverse of the Reynolds number. This technique has important advantages. The main one is the reduction in the computer space taken. Also it provides a measure of the relative importance of various terms in the equations and allows for an estimation of the difficulty of the problem.

6.4 Element Selection.

The Finite Element Method requires the flow domain to be subdivided into a collection of elements. In fluid mechanics the elements are characterized by the

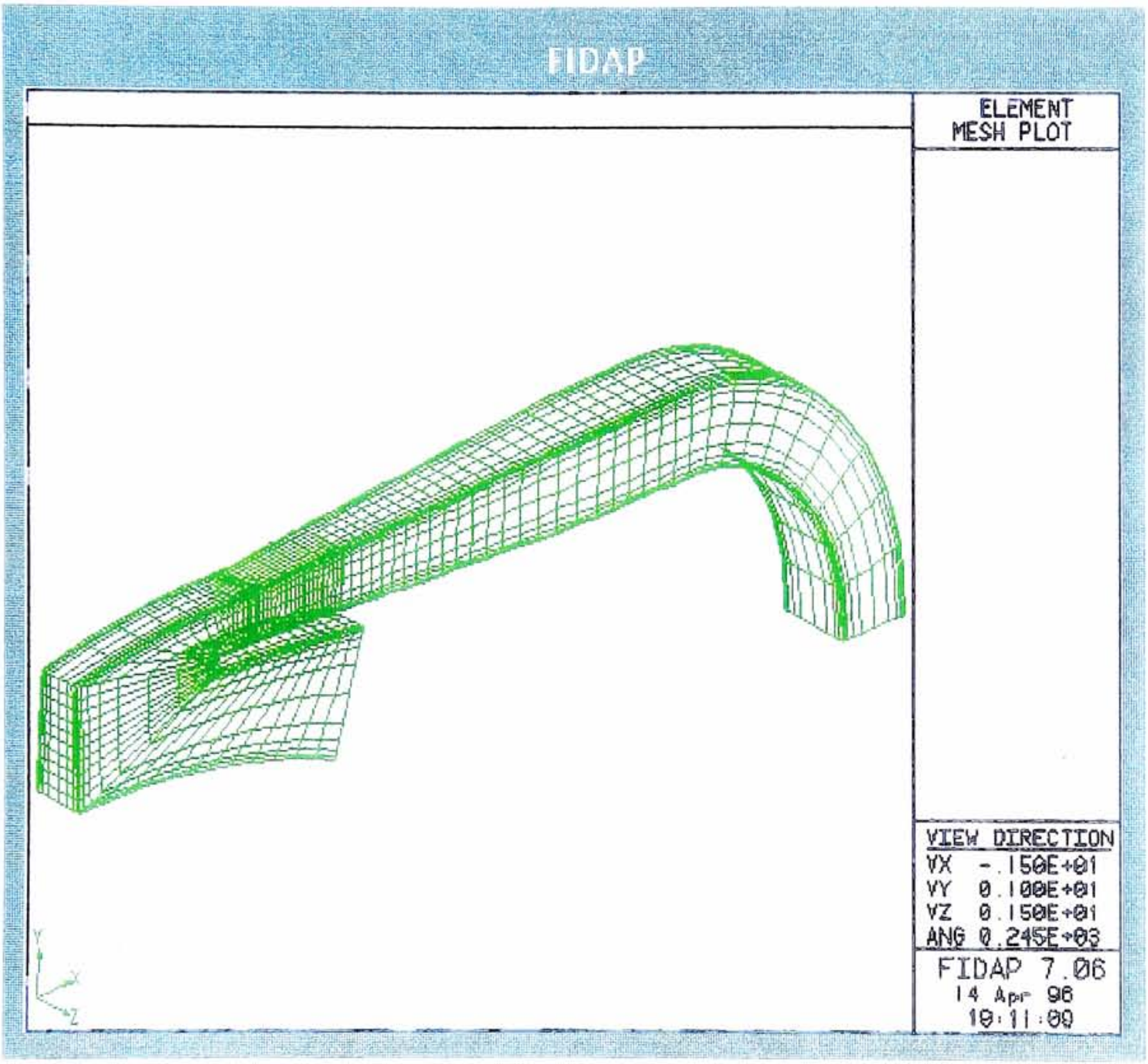


Figure 16 - Mesh.

velocity-pressure approximation used in them, as well as by their geometric shape. FIDAP has a library containing a wide spread of elements. For an analysis, the finite elements modeling the complete region are divided into groups, according to their type, their geometry, and the fluid property models used. Each element group must consist of the same type of elements and can use only one combination of fluid properties. Four basic types of element groups can be identified: fluid elements, porous elements, solid elements and boundary elements. The purpose of boundary element groups is to impose specialized boundary conditions such as convective heat and mass transfer, radiative heat transfer, normal/tangential velocity boundary conditions, turbulent near-wall conditions or free moving surfaces.

The elements chosen for this problem were eight noded bricks. These bricks use trilinear interpolation functions to approximate the velocity components allowing for a faster solution.

6.5 Solution Technique.

The solution technique used for this problem was the segregated algorithm which solves each conservation equation separately. This method is recommended for large scale simulations as the one this model involves. This is because the segregated solution algorithm decomposes the global matrix system into smaller sub matrices each governing the nodal unknowns associated with only one conservation equation. These smaller sub matrices are solved in a sequential manner using direct Gaussian elimination.

6.6 FIDAP Near Wall Model.

The purpose of the near wall model used by FIDAP is to eliminate the gap between the fully turbulent region beyond the buffer layer and the viscos sublayer.

To do this, special shape functions that capture the variations in the near wall region are employed. In order to get accurate results, this viscous sublayer should be fully enclosed in the elements closest to the wall.

6.7 Inlet and Boundary Conditions.

The inlet boundary conditions had to be calculated for three different inlets: inlet 1, inlet 2 and the fluid injection slits (see Figure 15). For inlet 1 the boundary conditions were calculated using velocity triangles. For inlet 2 the boundary conditions were set to be identical to the boundary conditions of outlet 2. The injected fluid velocity through the slits was calculated assuming the mass flow through a slit as a percentage of the inlet mass flow and relating this to the injection velocity by,

$$\dot{m}_{injection\%} = \rho u_{injection\%} A_{slit} \qquad \text{(Eq. 66)}$$

To clearly understand the behavior of the fluid in a turbopump diffuser and how the boundary conditions were calculated for inlet 1, it is important to define the velocity components of the fluid and impeller at the inlet and outlet sections. For this purpose it is useful to develop velocity triangles for the inlet and outlet flows.

In the idealized situation at the design point, flow relative to the rotor is assumed to enter and leave tangent to the blade profile at each section. Blade angles, β, are measured relative to the circumferential direction as shown in Figure 17-a. The inlet blade angle, β_1, fixes the direction of the relative inlet velocity at design conditions.

The impeller speed at inlet is defined as:

$$U_1 = \omega R_1 \qquad \text{(Eq. 67)}$$

The impeller speed at the inlet is specified by the impeller geometry and the machine operating speed. The absolute fluid velocity is the vector sum of the impeller velocity and the flow velocity relative to the blade. The absolute inlet velocity may be determined graphically as shown in Figure 17-b. The angle of the absolute fluid velocity, α_1 , is measured from the normal direction, as shown. The tangential component of the absolute velocity, V_{t1}, and the component normal to the flow area, V_{n1}, are also shown in Figure 17-b. The inlet blade angle may be specified for the design flow rate and pump speed to provide a shockless entry flow. Velocity triangles are constructed similarly at the outer section. The runner speed at the outlet is defined as:

$$U_2 = \omega R_2 \qquad \text{(Eq. 68)}$$

which again is known from the geometry and operating speed of the turbopump. The relative flow is assumed to leave the impeller tangent to the blades as shown in Figure 17-c. This assumption of perfect guidance fixes the direction of the relative outlet flow at design conditions.

For a centrifugal turbopump, the velocity relative to the blade generally changes in magnitude from inlet to outlet. The continuity equation must be applied, using the impeller geometry, to determine the normal component of velocity at each section. The normal component, together with the outer blade angle, is sufficient to establish the velocity relative to the blade and the impeller velocity as shown in Figure 17-c.

The inlet and outlet velocity triangles provide all the information needed to

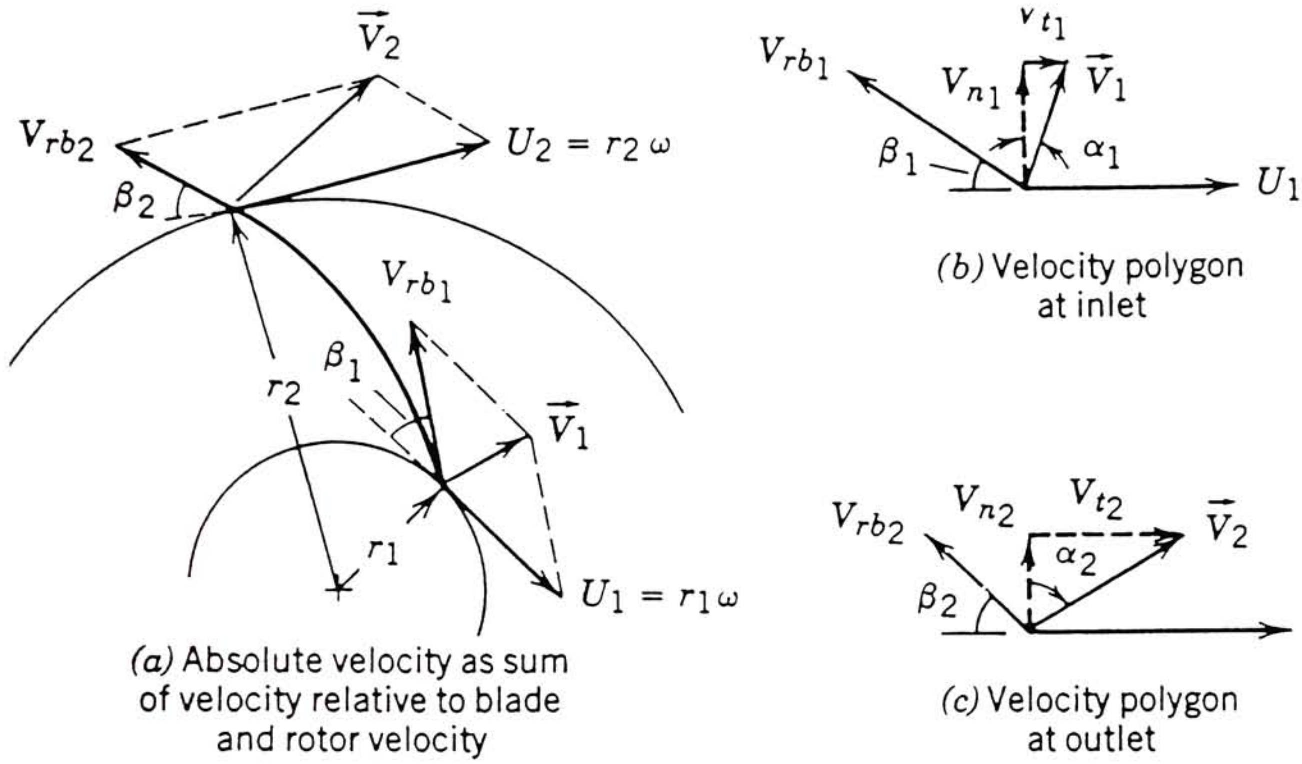


Figure 17 - Velocity Triangles.

calculate the ideal torque or power, absorbed or delivered by the impeller using the following equations:

$$T_{shaft} = (r_2 V_{t2} - r_1 V_{t1})\dot{m} \quad \text{(Eq. 69)}$$

$$\dot{W}_m = \omega T_{shaft} = \omega (r_2 V_{t2} - r_1 V_{t1})\dot{m} \quad \text{(Eq. 70)}$$

The results represent the performance of a turbomachine under idealized conditions at the design operating point, since it is assumed that all flows are uniform at each section and that they enter and leave the rotor tangent to the blades. These idealized results represent the upper limits of performance for a turbomachine.

In order to have inlet 2 and outlet 2 with the same boundary conditions, FIDAP's BcPeriodic Command was used. This command allows you to specify all degrees of freedom to be identical in the reference area (outlet 2) and the periodic area (inlet2). Thus, any boundary condition applied to the reference node is automatically applied to the periodic node and any active degree of freedom at the reference node has the identical solution at both nodes.

The values for the kinetic energy and dissipation were found using equations provided by R. Martinuzzi and A. Pollard for turbulent pipe flows [1].

$$k = 0.005 V_{in}^2 \quad \text{(Eq. 71)}$$

$$\varepsilon = \frac{U k^{3/2}}{0.03 D_h} \quad \text{(Eq. 72)}$$

In order to obtain its dimensionless value the following formulas were used:

$$k^{*} = k * k_c \quad , \quad V_c^2 = V_{in}^2 \quad , \quad k_c = 1/V_c^2$$

to obtain a value of $k^{*} = 0.005$

The same way the following formulas were used:

$$\varepsilon^{*} = \varepsilon * \varepsilon_c \quad , \quad \varepsilon_c = \frac{L_c}{V_c^3} \quad , \quad C_u = 0.09 \quad , \quad L_c = D_h$$

to obtain a value of $\varepsilon^{*} = 0.001$

Refer to Appendix A and Appendix C for the calculations for the flow conditions and boundary conditions and for the input files used for each model respectively.

CHAPTER 7. RESULTS.

The results presented here are for the three-dimensional finite element model of the vaneless and vaned sections of the MK49-F turbopump. The first set of results are those corresponding to the design flow rate and to the 20% and 60% off-design flow rates through the diffuser without fluid injection. In the second set of results, the application of fluid injection was implemented to determine how effective the boundary layer control of fluid injection is in reducing the flow separation in the diffuser.

7.1. Design Flow Case.

The purpose of this case is to establish it as a baseline for comparison which will allow us to compare these results to the ones that will be obtained at off-design flow conditions and to study the effectiveness of fluid injection.

For each flow case several plots were made. The first one is the velocity vector plot on the symmetry plane (Figure 18). This Figure shows an area of reduced velocity in the diffuser's outlet near the bottom plane. The same effect, relatively increased, can be seen in the velocity vector plots on the shroud side plane (Figure 19) and on the bottom plane (Figure 20). The velocity vector plot on the shroud side plane is 0.07 mm away from the shroud side wall in the diffuser's inlet and 0.8988 mm in the diffuser's outlet. The velocity vector plot on the bottom plane is 0.07 mm away from the bottom plane in the diffuser's inlet and 0.8988 mm in the diffuser's outlet. In order to study this information more clearly, the perpendicular views of the velocity vector on the shroud side plane (Figure 21) and the bottom plane (Figure 22) were made. From these two plots it is easy to observe the area of reduced velocity without flow separation. To verify that flow separation is not occurring, two close-up views of the velocity vector plot on the shroud side plane (Figure 23) and of the bottom plane (Figure 24) were made. From these two plots it can be seen that there is no flow separation in the diffuser and that the area of reduced velocity is all along the bottom plane near the shroud side.

Flow separation was not found in the diffuser, but it was found in the shroud side of the vaneless entrance region (Figure 25), which can be attributed to the secondary flow effects in this area. This has an impact in the diffuser's performance since the fluid entering the diffuser is not uniform. The pressure contour plot (Figure 26) and the pressure along the centerline (Figure 27) indicate a relatively uniform conversion of dynamic head to static pressure as the diffuser is traversed in the direction of flow. Using the pressure line plots from the bottom of the diffuser to the top, at the diffuser inlet (Figure28) and outlet (Figure 29), the pressure recovery coefficient was calculated to be 0.63. The value of the inlet pressure is affected by the separation in the vaneless region and the value of the outlet pressure is affected by the flow retardation in the bottom plane of the diffuser.

The kinetic energy (Figure 30), dissipation (Figure 31), and vorticity (Figure 32) contour plots are included for flow verification. The majority of the kinetic energy is generated at the top and bottom planes near the shroud side wall, with a corresponding amount of dissipation in the same area. The vorticity (Figure 32), which is an indication of the level of viscosity present in the fluid at a particular location, is lower on the top surface. This is caused by the fluid's angle of entrance into the diffuser. The velocity profiles that were graphed at positions near the diffuser inlet (Figure 33) and outlet (Figure 34) of the diffuser on the symmetry plane and are typical of turbulent flow in a diffuser. The inlet velocity profile shows the flow separation that occurs in the entrance to the vaneless section and the outlet velocity profile shows the significant reduction in the flow speed that is present in the diffuser's bottom plane near the shroud and hub sides.

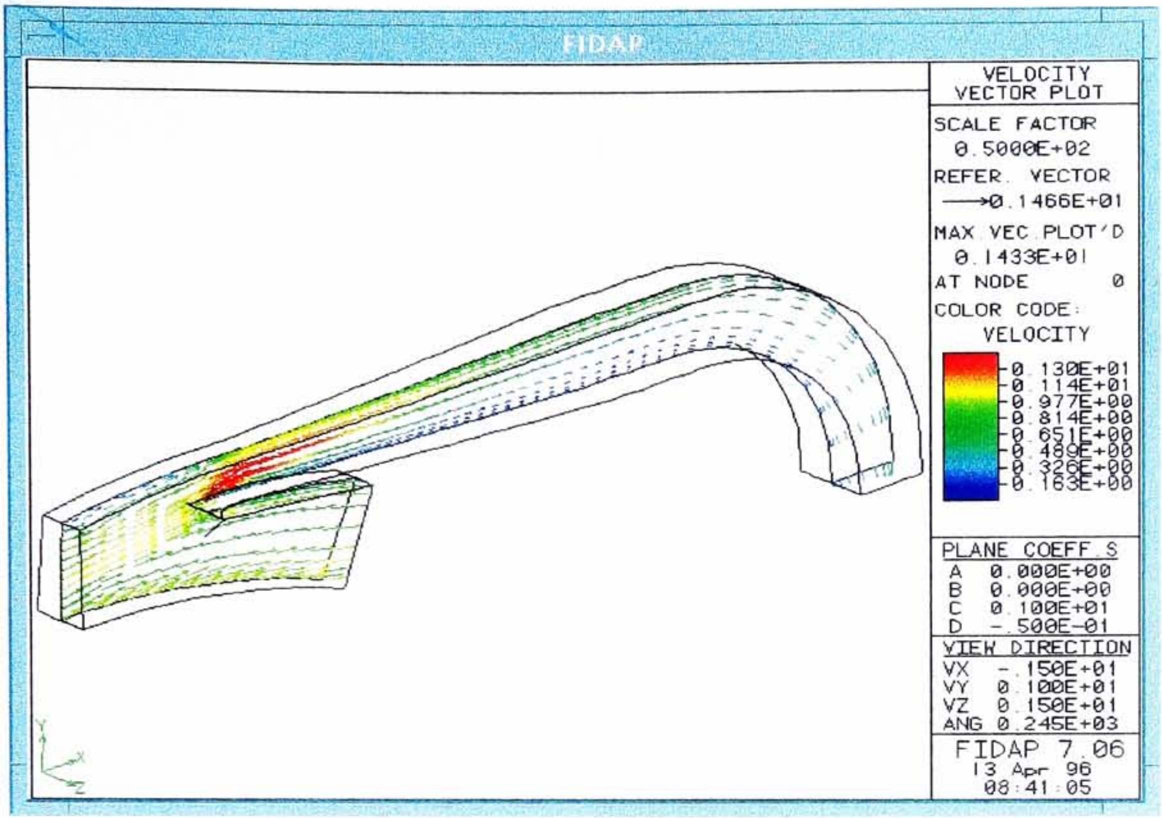


Figure 18 - Velocity on Symmetry Plane (Design Flow)

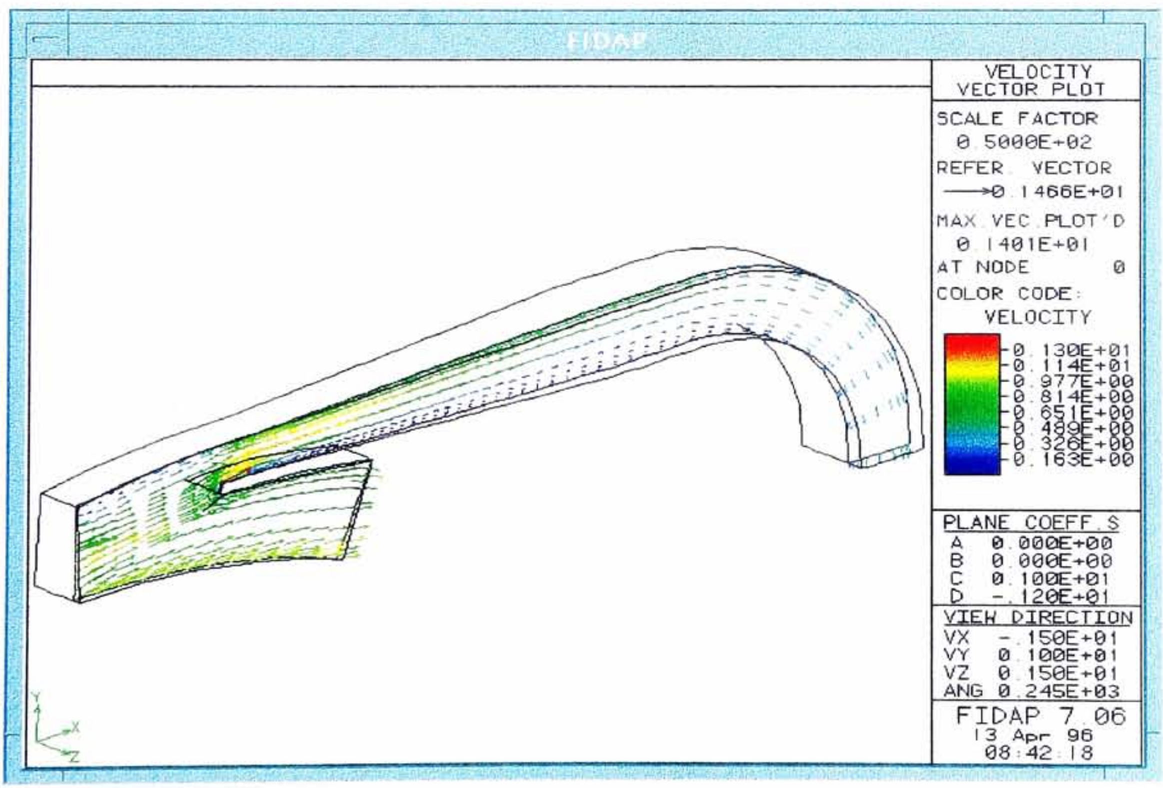


Figure 19 - Velocity on Shroud Side Plane (Design Flow)

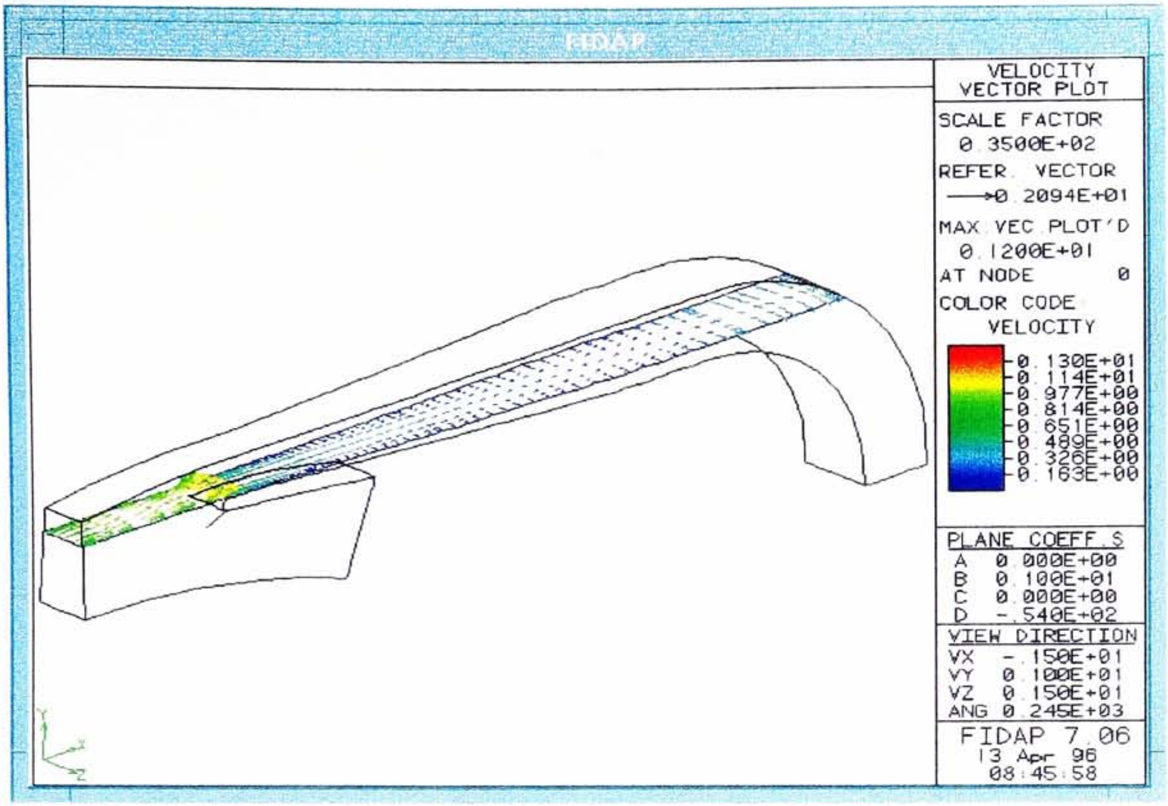


Figure 20 - Velocity on Bottom Plane (Design Flow)

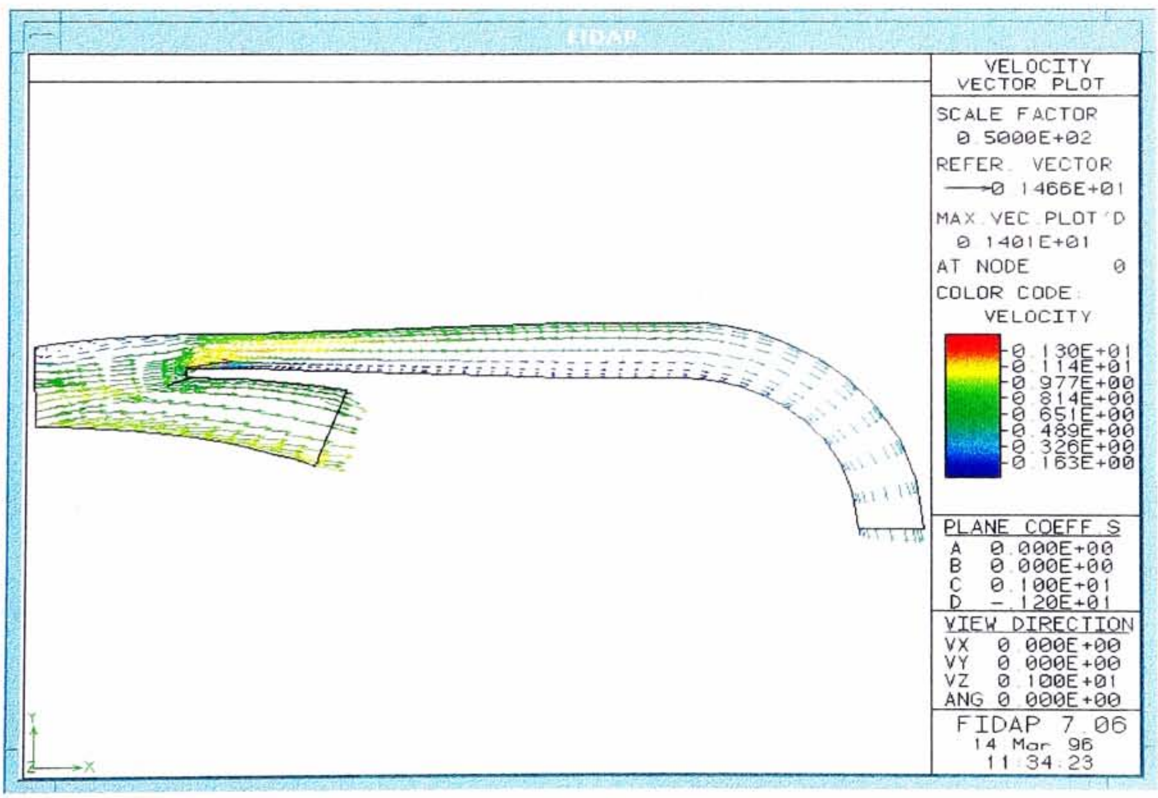


Figure 21 - 2-D View of Velocity on Shroud Side (Design Flow)

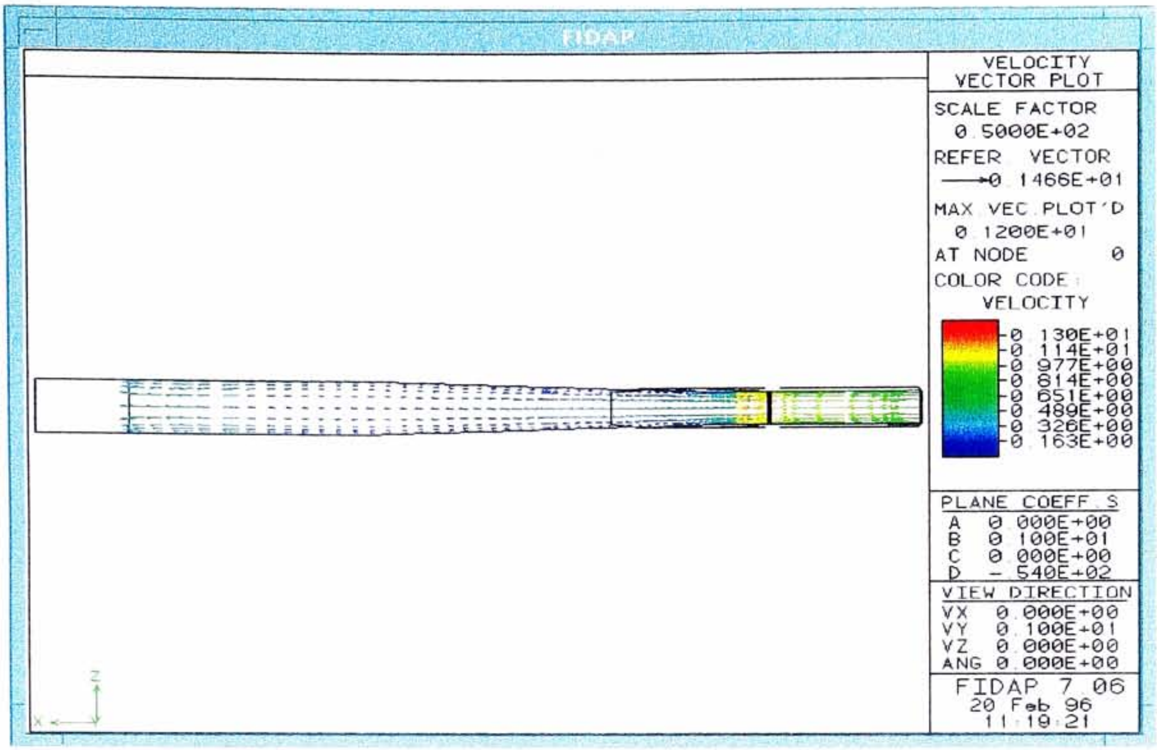


Figure 22 - 2-D View of Velocity on Bottom (Design Flow)

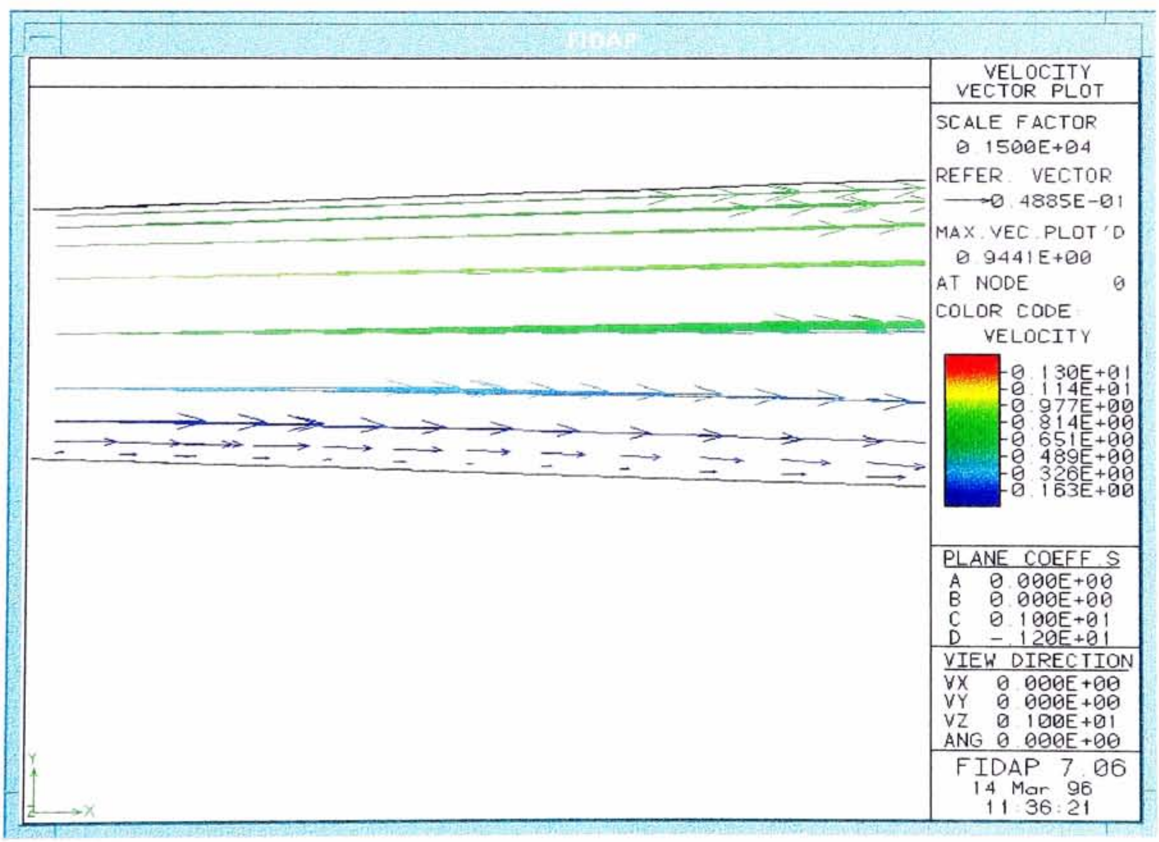


Figure 23 - Velocity at Outlet on Shroud Side (Design Flow)

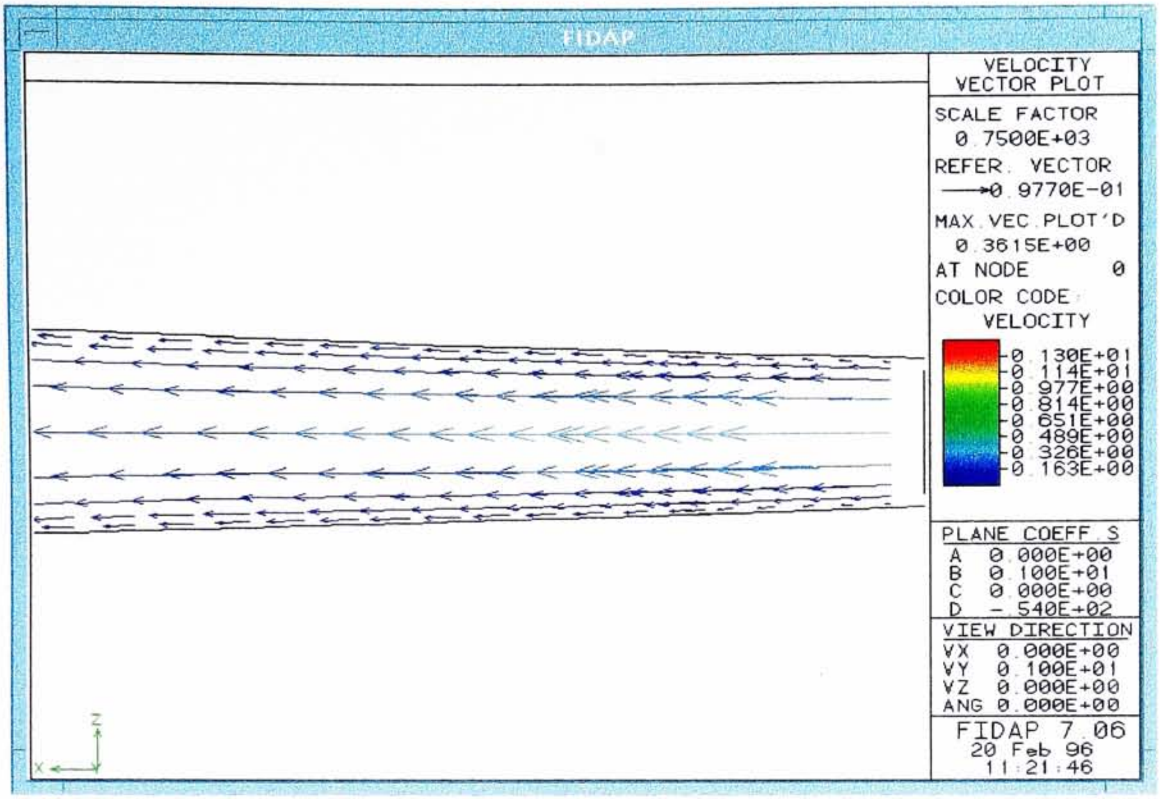


Figure 24 - Velocity at Outlet on Bottom (Design Flow)

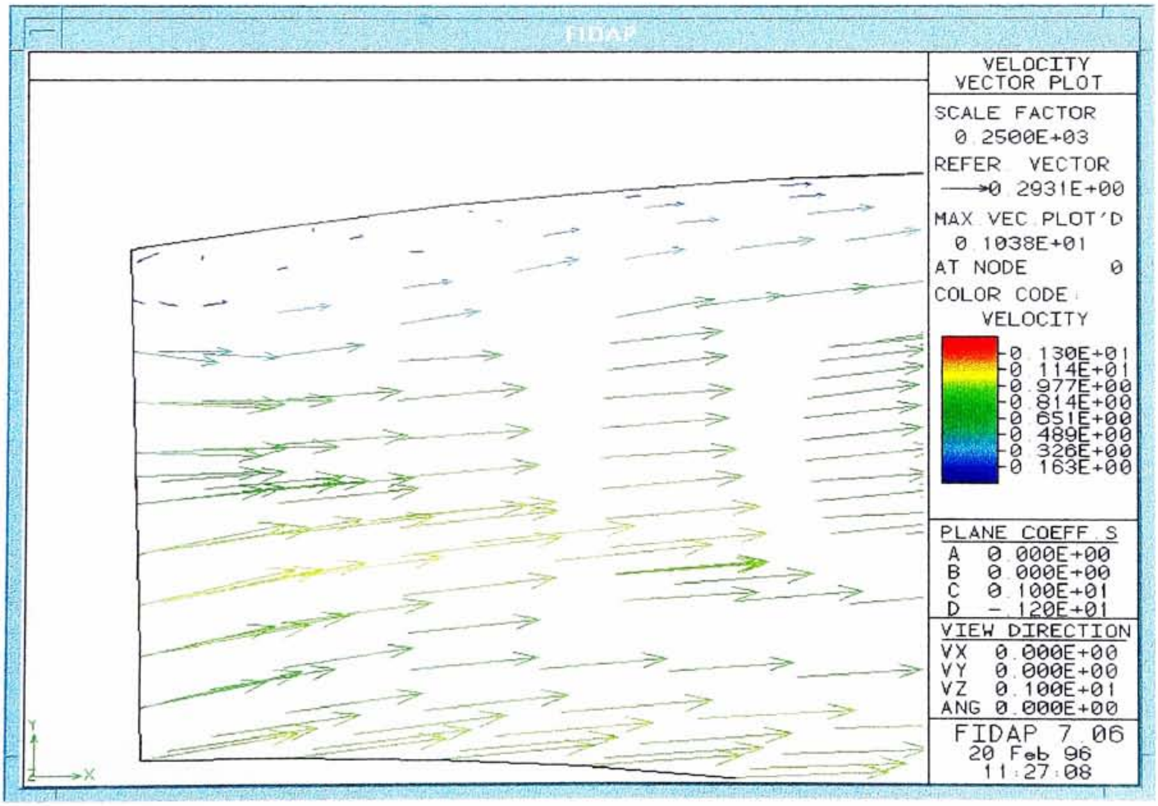


Figure 25 - Velocity at Inlet on Shroud Side (Design Flow)

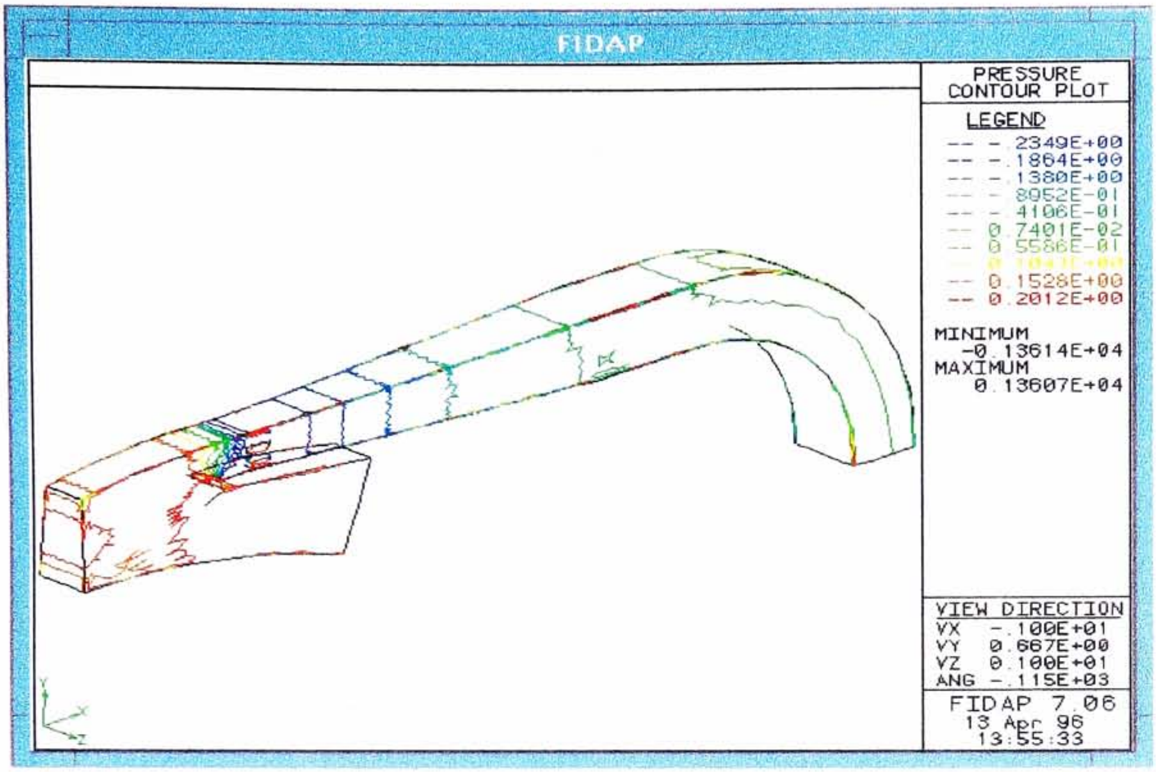


Figure 26 - Pressure Contour (Design Flow)

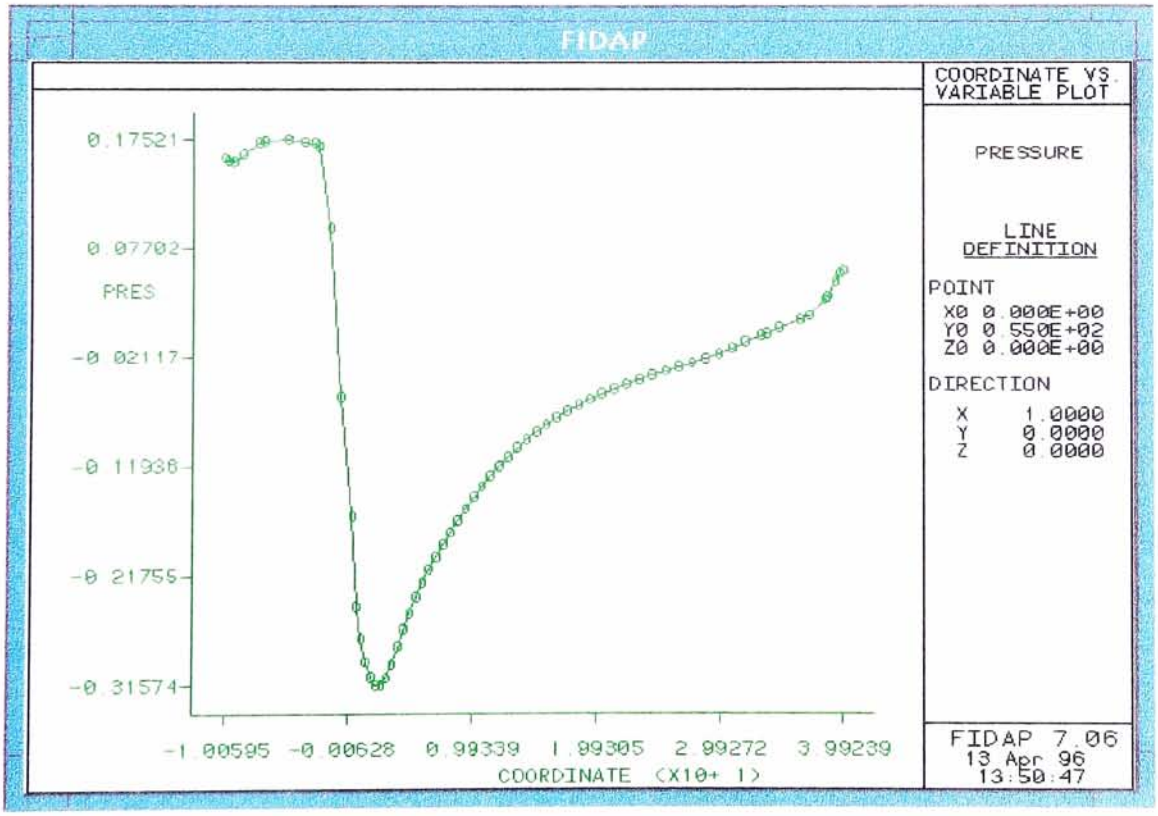


Figure 27 - Pressure Along Centerline (Design Flow)

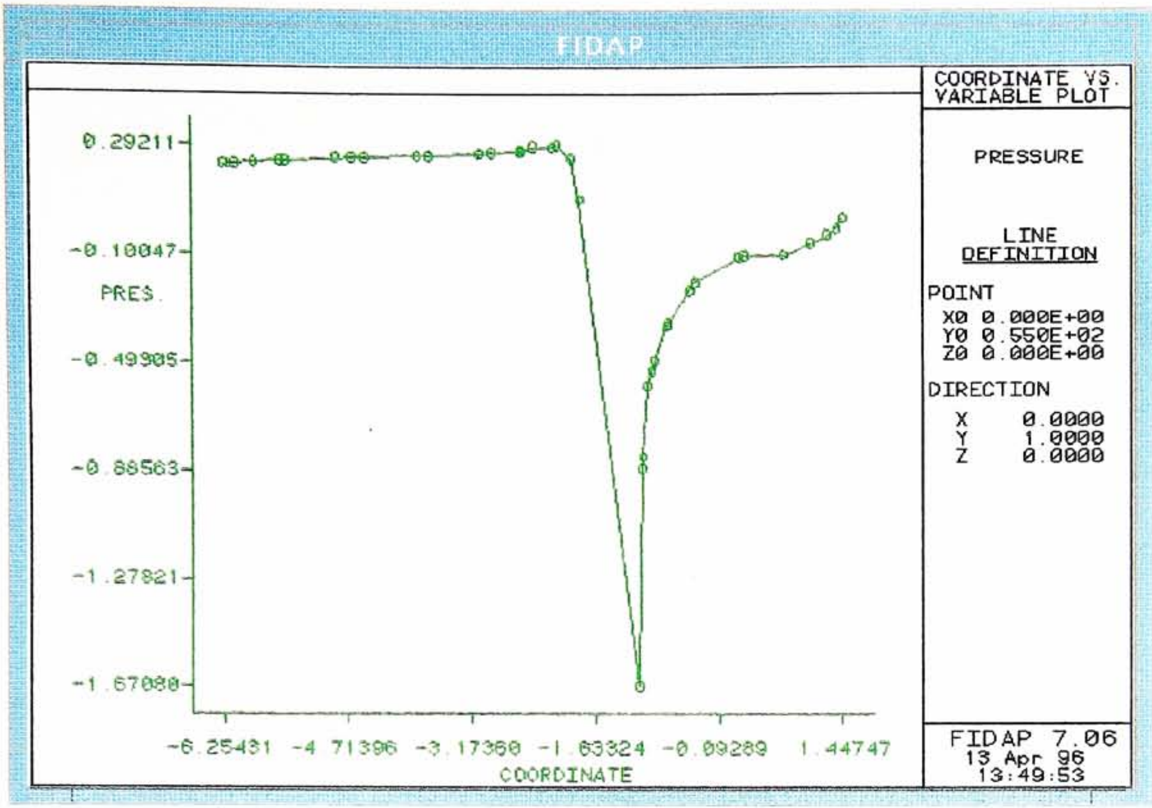


Figure 28 - Inlet Pressure (Design Flow)

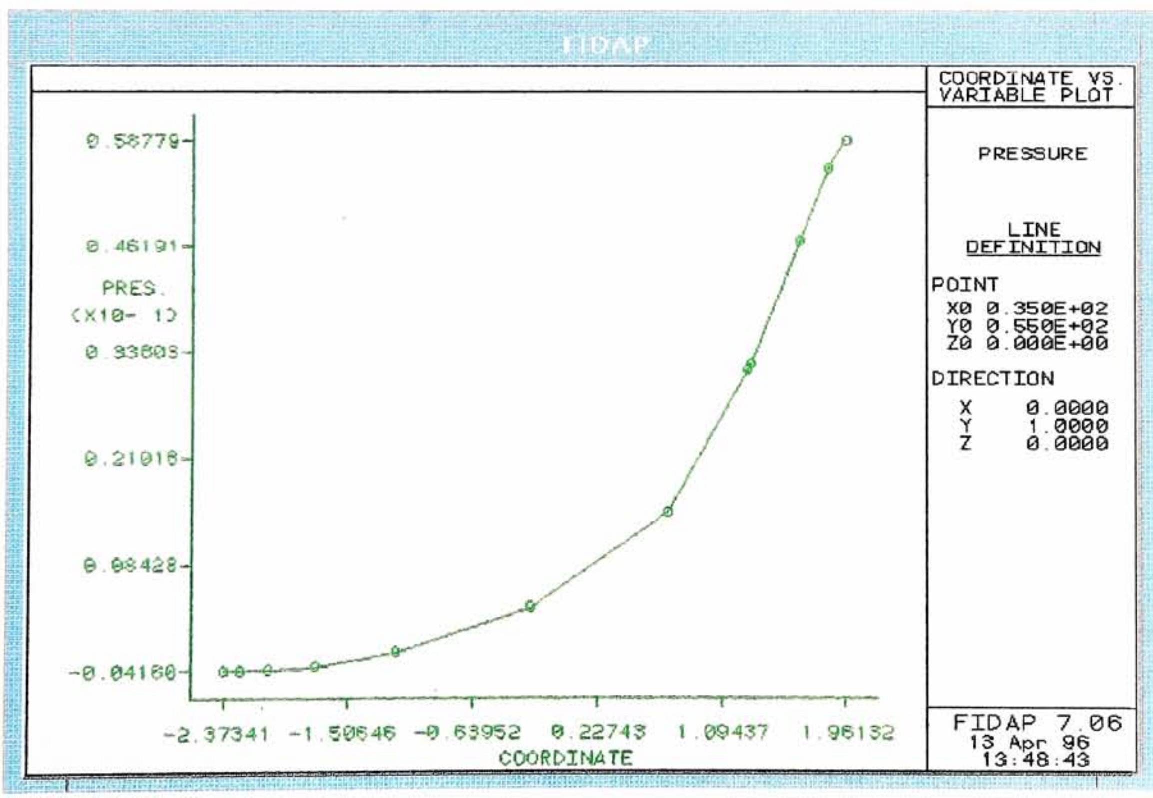


Figure 29 - Outlet Pressure (Design Flow)

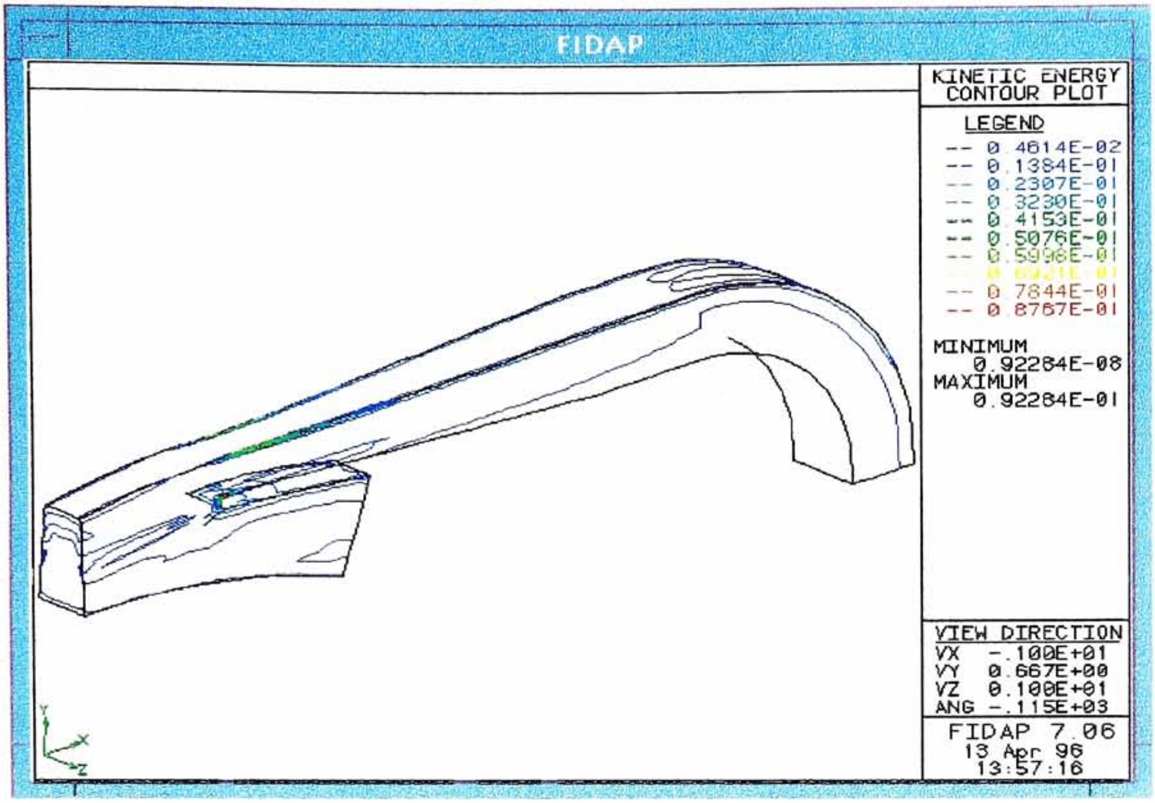


Figure 30 - Kinetic Energy Contour (Design Flow)

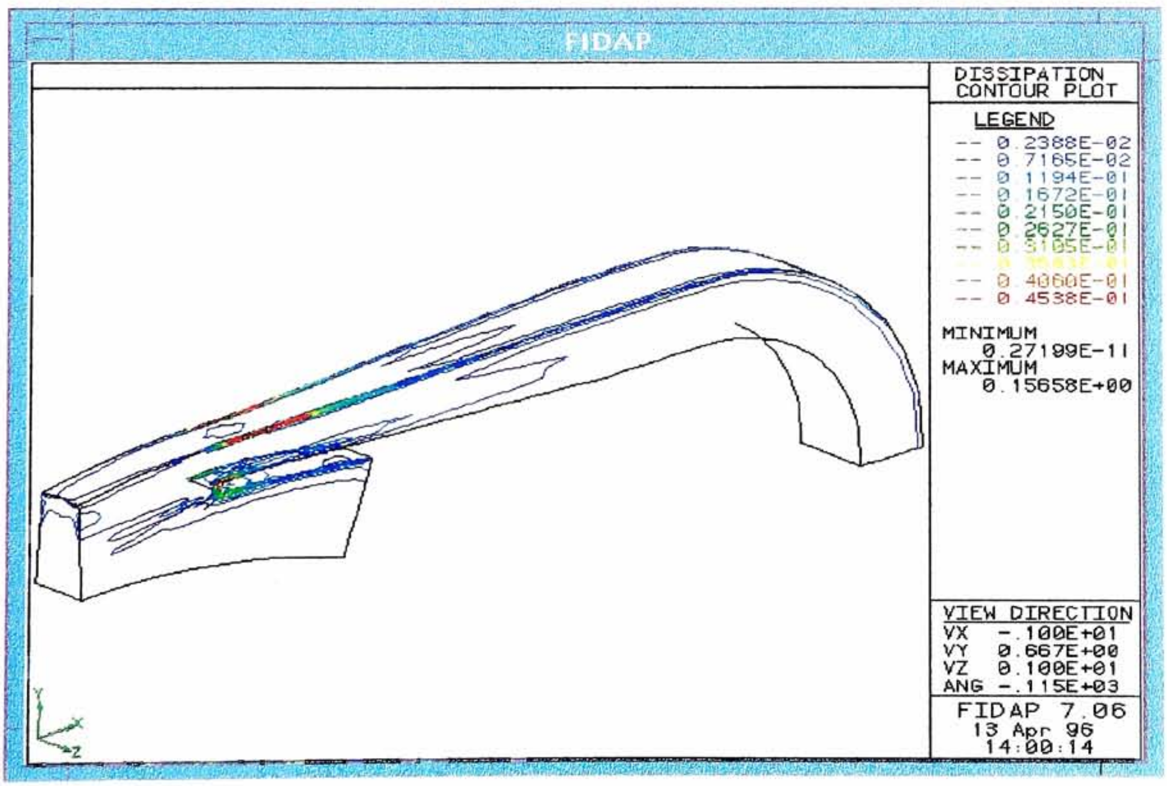


Figure 31 - Dissipation Contour (Design Flow)

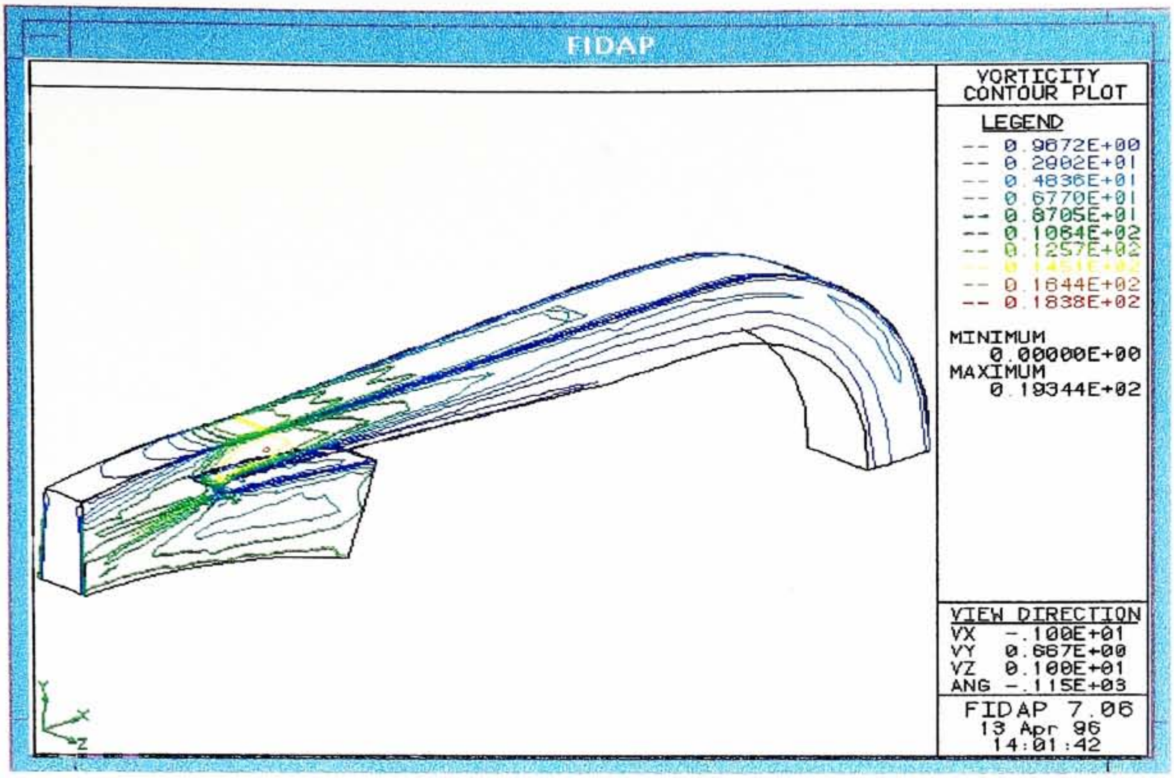


Figure 32 - Vorticity Contour (Design Flow)

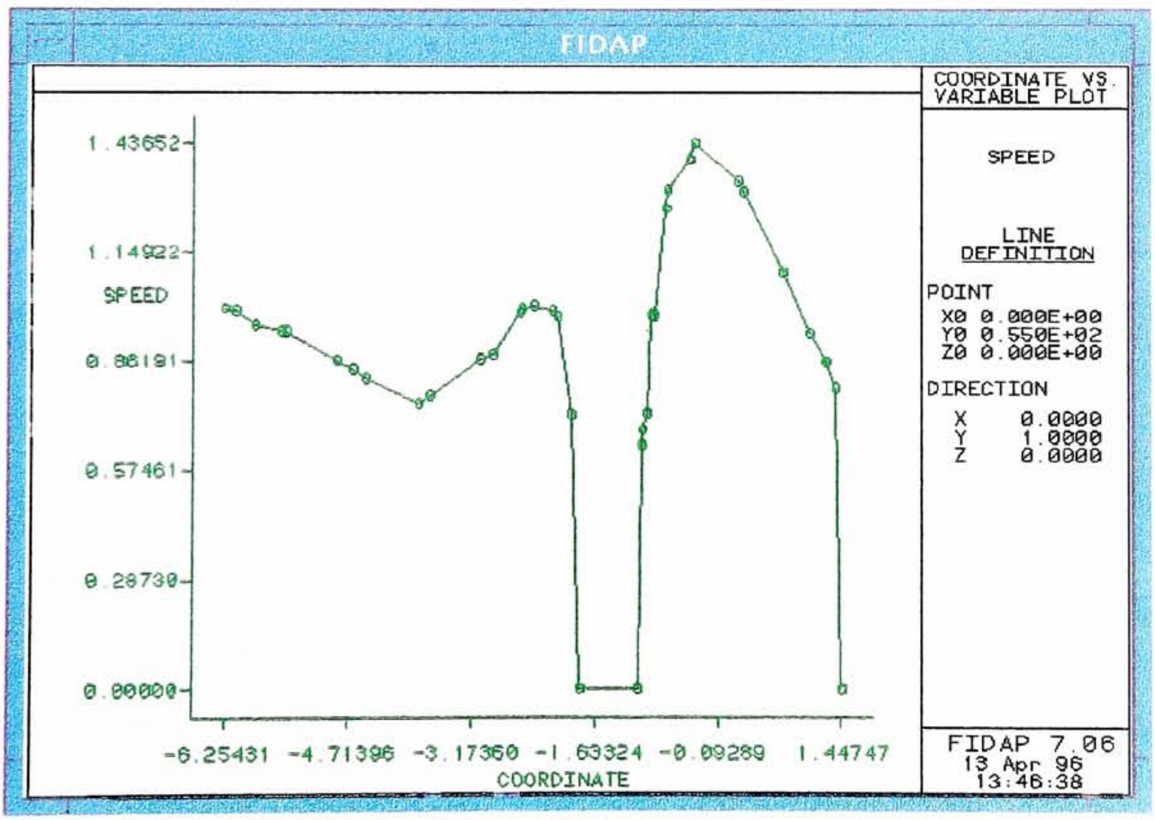


Figure 33 - Inlet Velocity Profile (Design Flow)

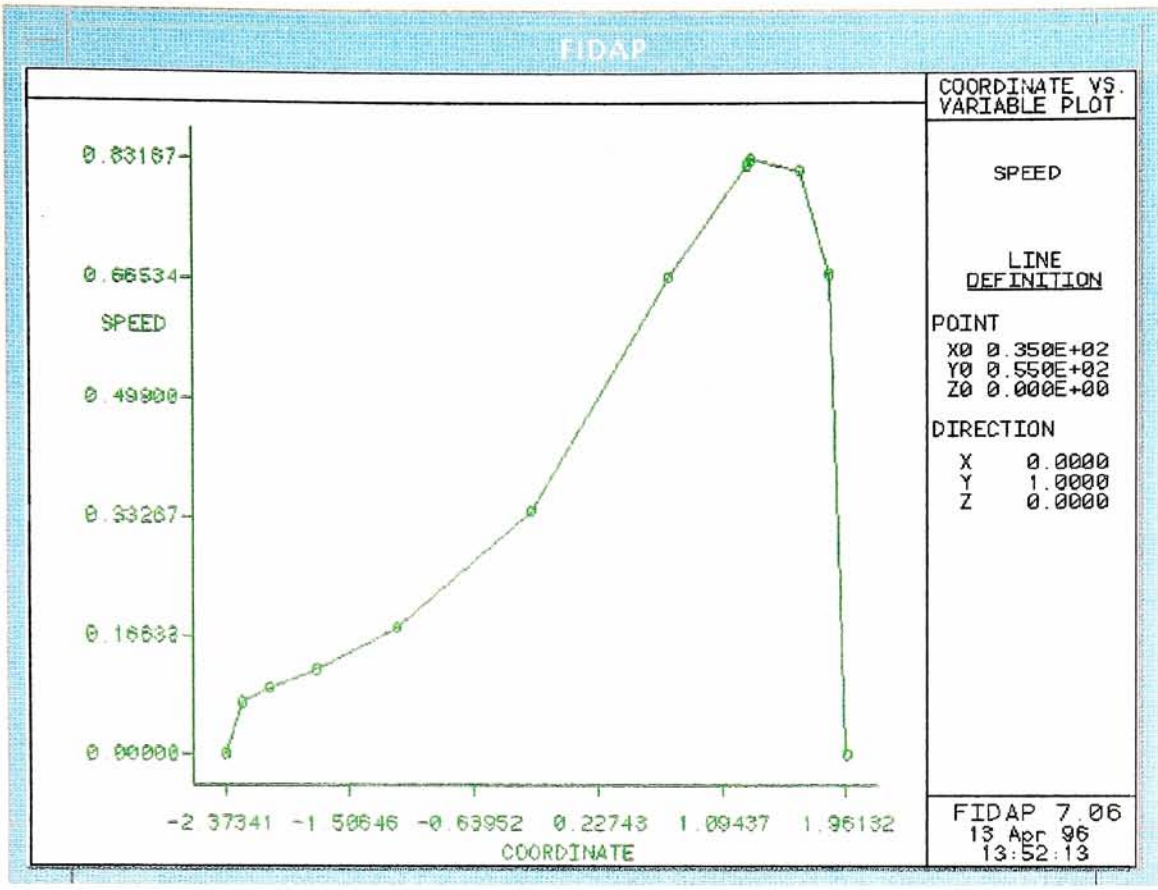


Figure 34 - Outlet Velocity Profile

7.2. 60% of Design Flow.

In order to obtain off-design flow conditions associated with possible flow separation, the flow rate was set to 60% of the design flow. This flow rate would guarantee, as Yoshida [2] proved, that flow separation and diffuser stall would occur allowing for the determination of the critical areas where the stall was occurring.

The first plot is the velocity vector on the symmetry plane (Figure 35). This Figure shows an area of reduced fluid velocity and possibly of flow separation in the diffuser's outlet, near the bottom plane. The same effect, relatively increased, can be seen in the velocity vector plots on the shroud side plane (Figure 36) and on the bottom plane (Figure 37). To get a better idea of where the flow separation was occurring, planes were cut through the diffuser to observe the velocity vector plots. For comparison purposes, these planes were cut at the same locations as in the design flow case. The perpendicular views of the velocity vector on the shroud side plane (Figure 38) and the bottom plane (Figure 39) were made, to observe the area of reduced velocity although it is not possible to observe if there is any flow separation. To verify that flow separation is occurring, two close-up views of the velocity vector plot on the shroud side plane (Figure 40) and on the bottom plane were made (Figure 41). From these two plots it can be seen a pocket of separated flow that begins at the bottom wall near the shroud side and then increases in size and intensity as flow separation builds up and diffuser stall occurs. This is in part due to the effect of secondary flows, which can be described through the three dimensional nature of the flow. The main fluid flow is along the length of the diffuser, but fluid motion is also found in the y- and z- directions. A swirling flow downward in the y-direction circulating toward the shroud side wall in the z-direction is the best way to describe this secondary fluid motion. This can be seen clearly in Figure 41, where the fluid particles near the shroud side plane have slowed down considerably in comparison to the fluid particles near the symmetry plane. Once the flow gets to the turning channel it adheres to the inner wall around the bend.

The flow separation found in the shroud side of the vaneless region (Figure 42) can be attributed also to secondary flow effects. This has an impact in the diffuser's performance since the fluid entering the diffuser is not uniform. The pressure contour plot (Figure 43) and the pressure line along the centerline (Figure 44) indicate a relatively uniform conversion of dynamic head to static pressure as the diffuser is traversed in the direction of flow. Using the pressure line plots at the diffuser inlet (Figure 45) and outlet (Figure 46), the pressure recovery coefficient was calculated to be 0.56. The value of the inlet pressure is affected by the flow separation found in the diffuser's vaneless region and the value of the outlet pressure is affected by the flow separation in the bottom plane of the diffuser. The flow separation and diffuser stall are an indication that the static pressure recovery will not be as high as desired.

The kinetic energy (Figure 47), dissipation (Figure 48), and vorticity (Figure 49) contour plots are included for flow verification. The majority of the kinetic energy is generated at the top plane near the shroud side wall, with a corresponding amount of dissipation in the same area. The vorticity, which is an indication of the level of viscosity present in the fluid at a particular location, is very high in the entrance region near the diffuser's top plane. The velocity profiles that were graphed at positions near the diffuser inlet (Figure 50) and outlet (Figure 51) of the diffuser on the symmetry plane and are typical of turbulent flow in a diffuser.

The inlet velocity profile shows the flow separation that occurs in the vaneless region and the outlet velocity profile shows the significant reduction in the flow speed that is present in the diffuser's bottom plane.

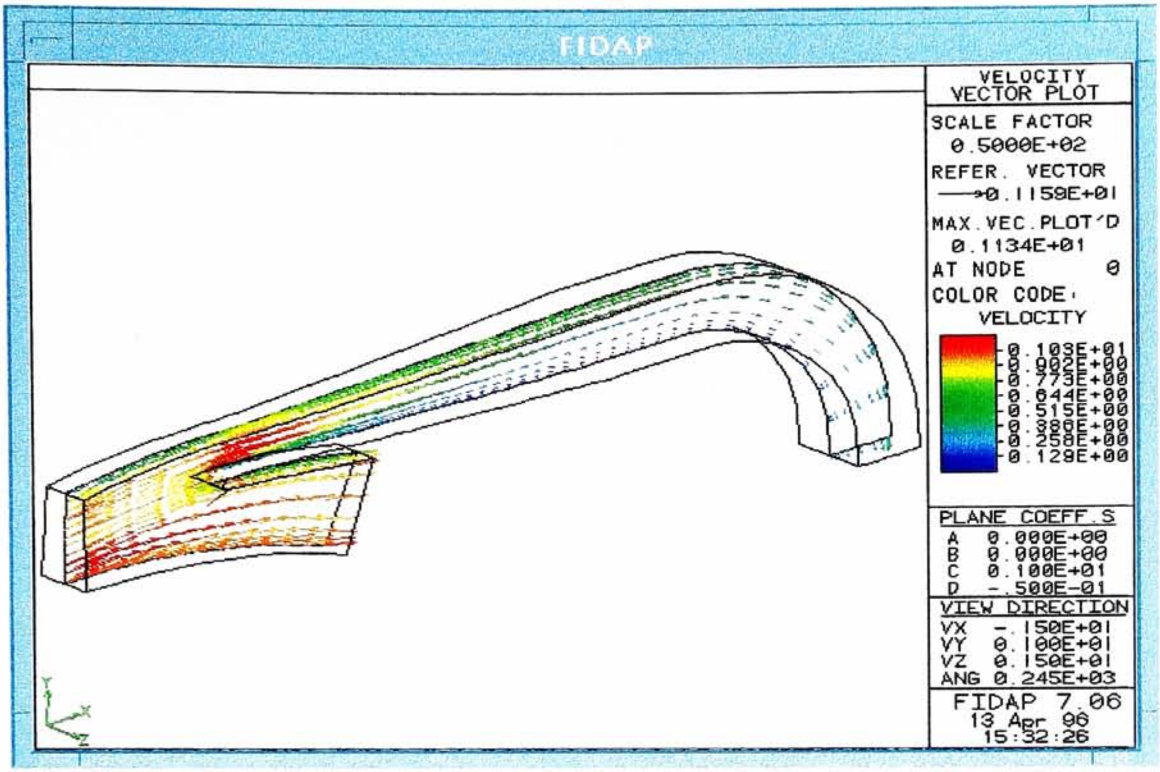


Figure 35 - Velocity on Symmetry Plane (60% of Design Flow)

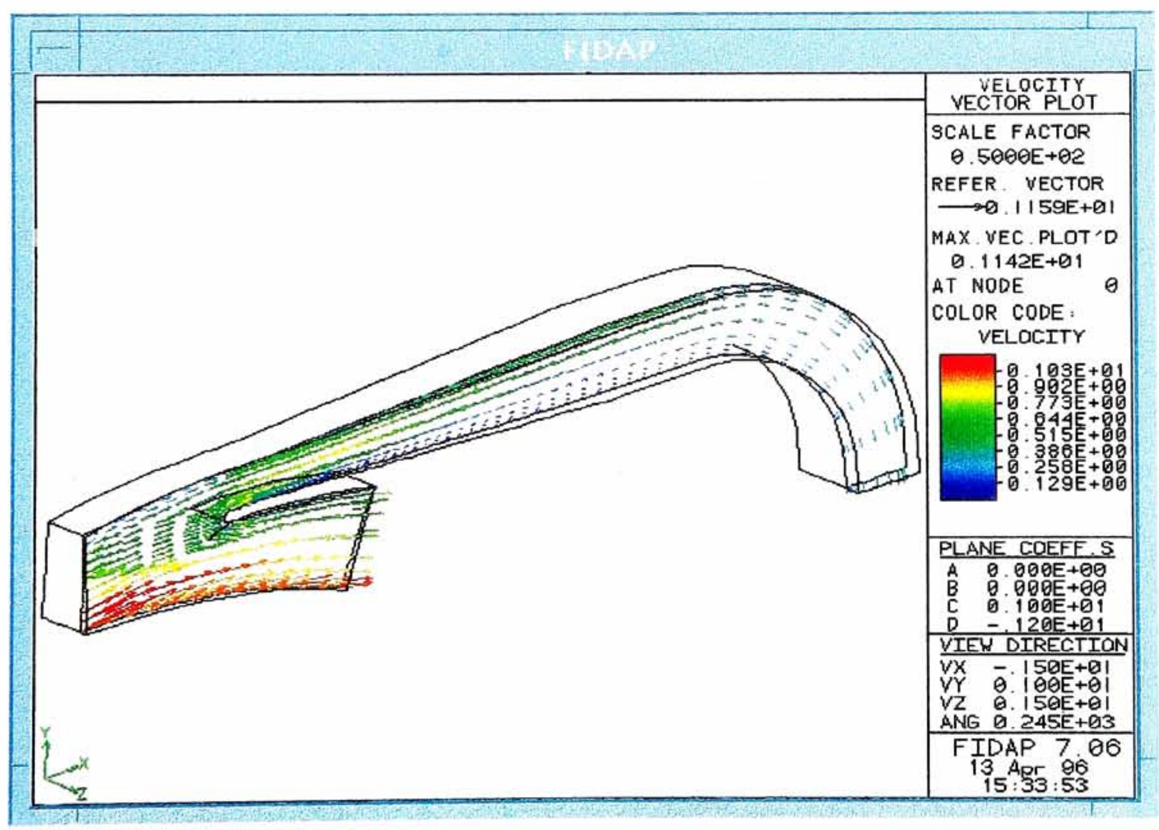


Figure 36 - Velocity on Shroud Side Plane (60% of Design Flow)

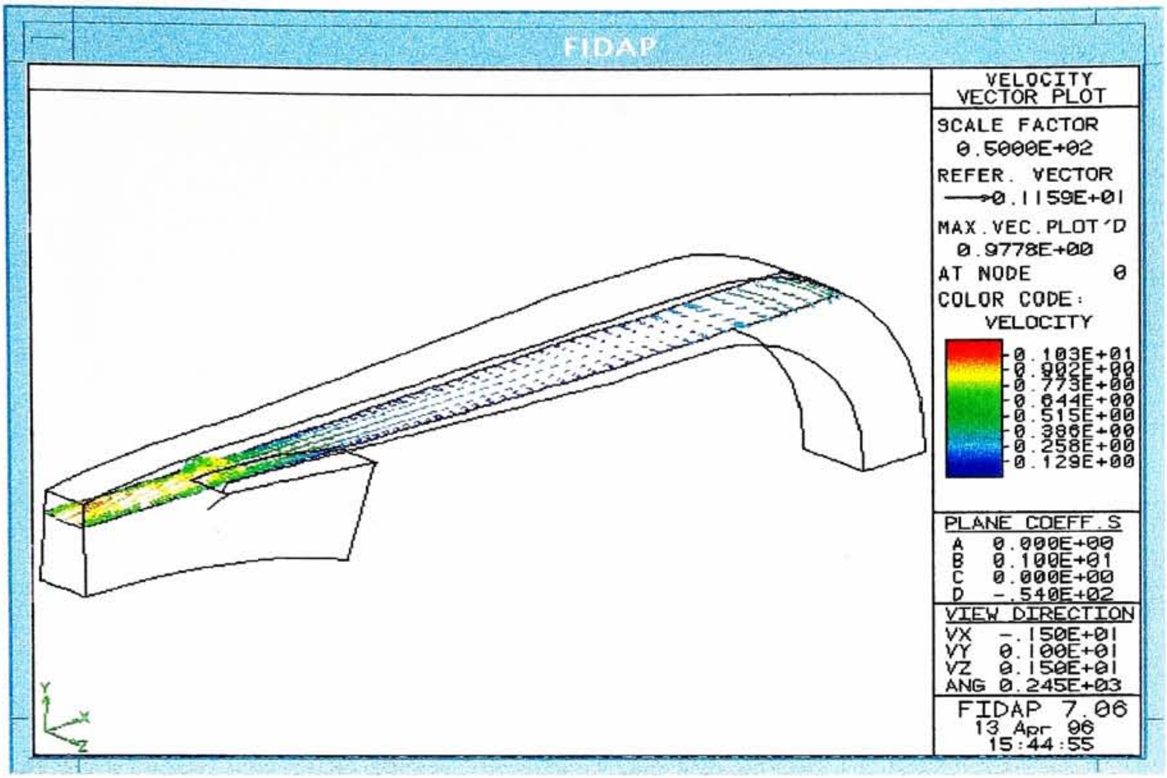


Figure 37- Velocity on Bottom Plane (60% of Design Flow)

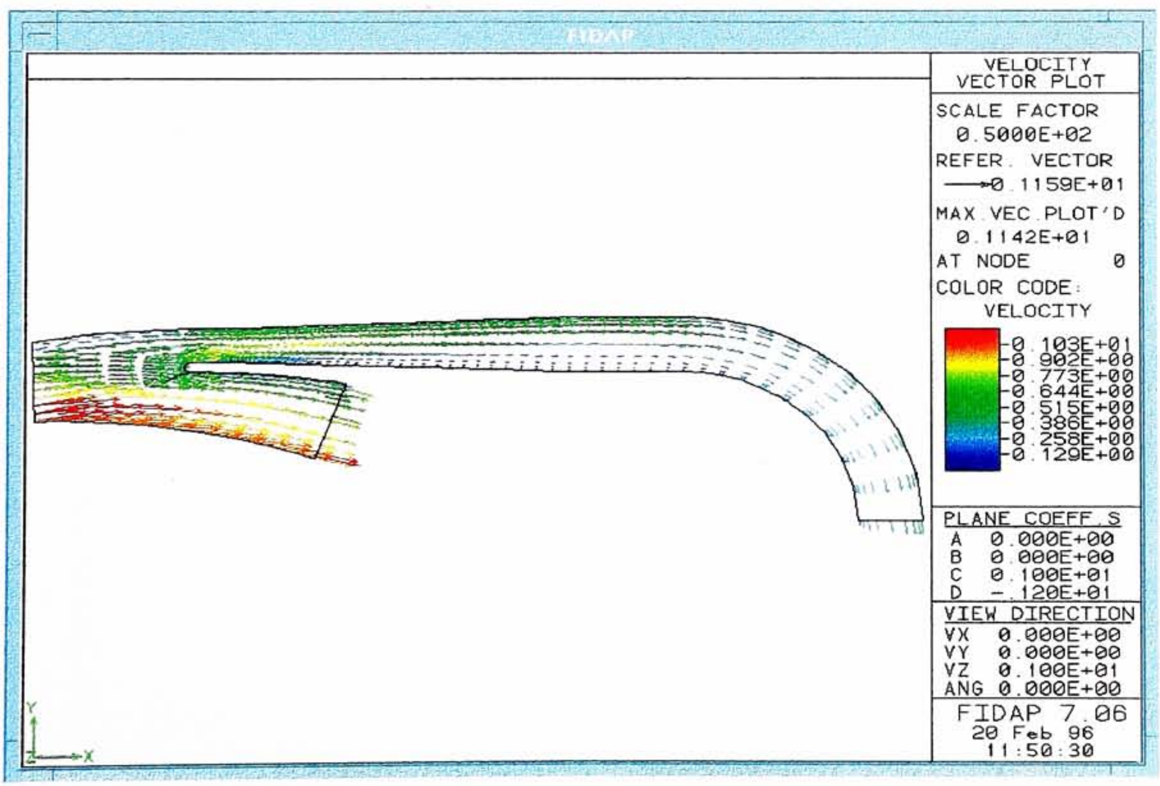


Figure 38 - 2-D View of Velocity on Shroud Side (60% of Design Flow)

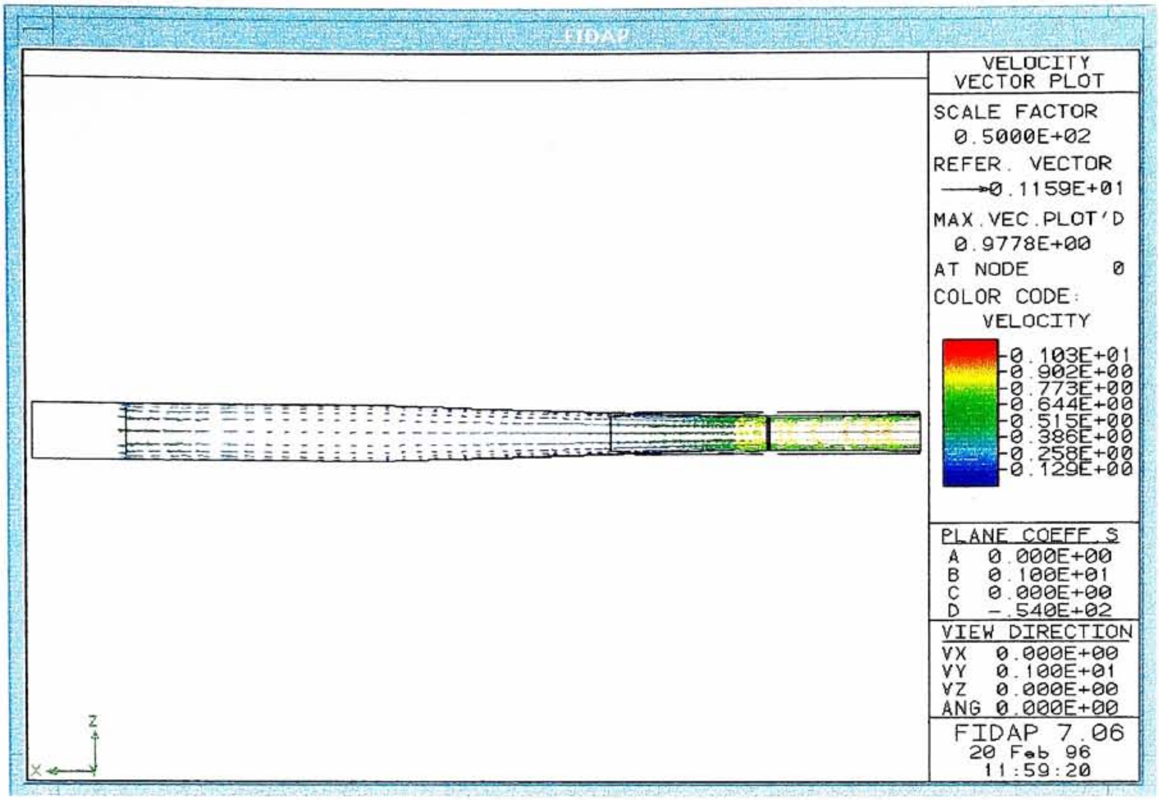


Figure 39 - 2-D View of Velocity on Bottom (60% of Design Flow)

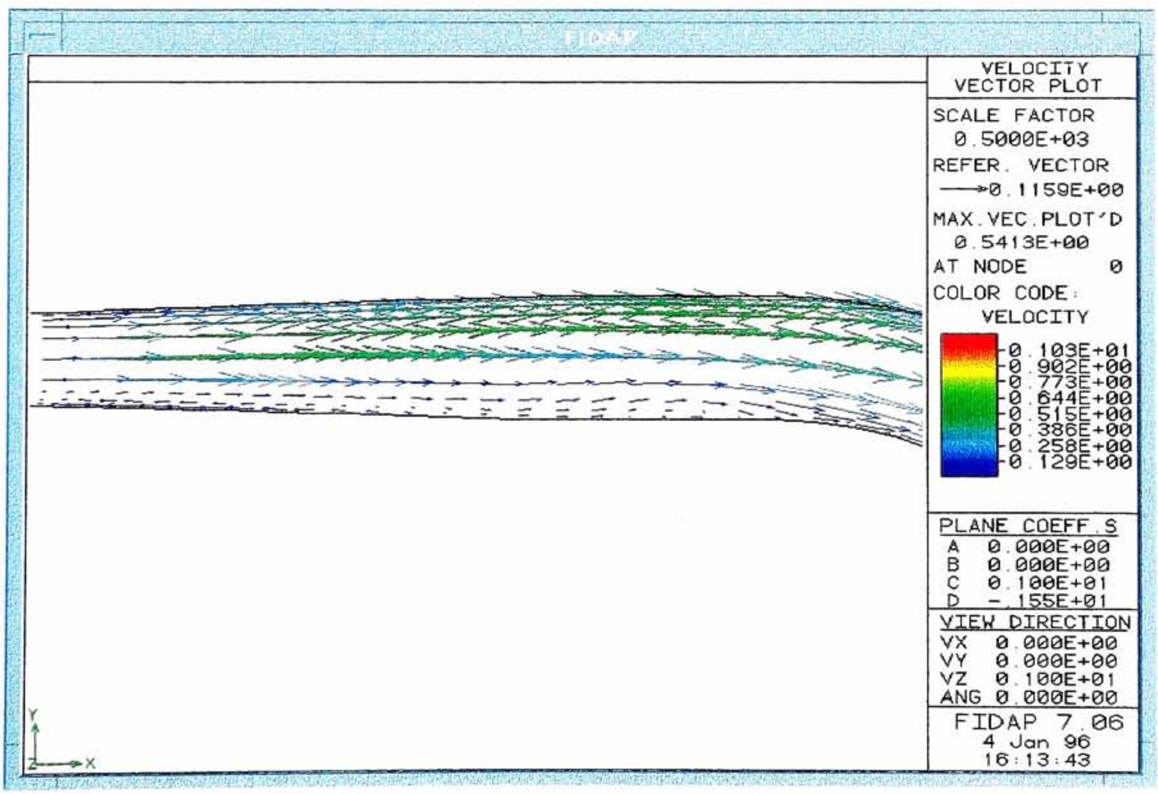


Figure 40 - Velocity at Outlet on Shroud Side (60% of Design Flow)

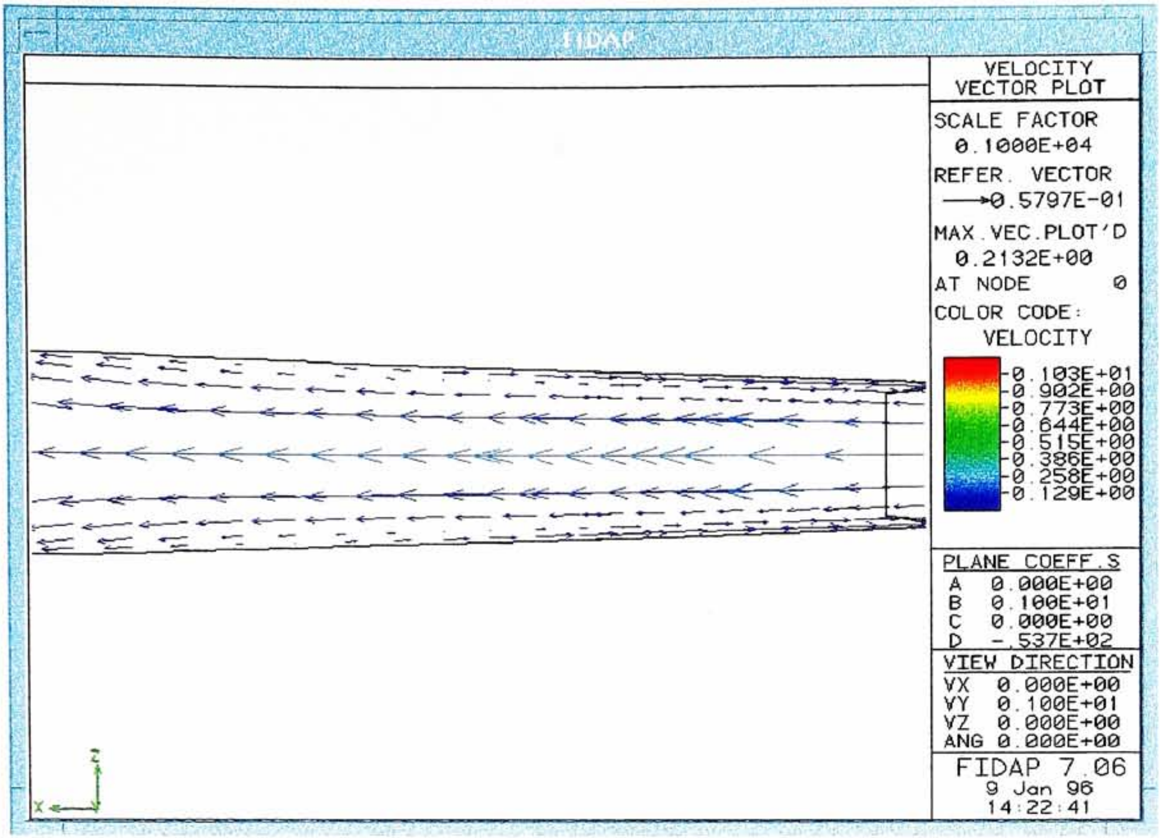


Figure 41 - Velocity at Outlet on Bottom (60% of Design Flow)

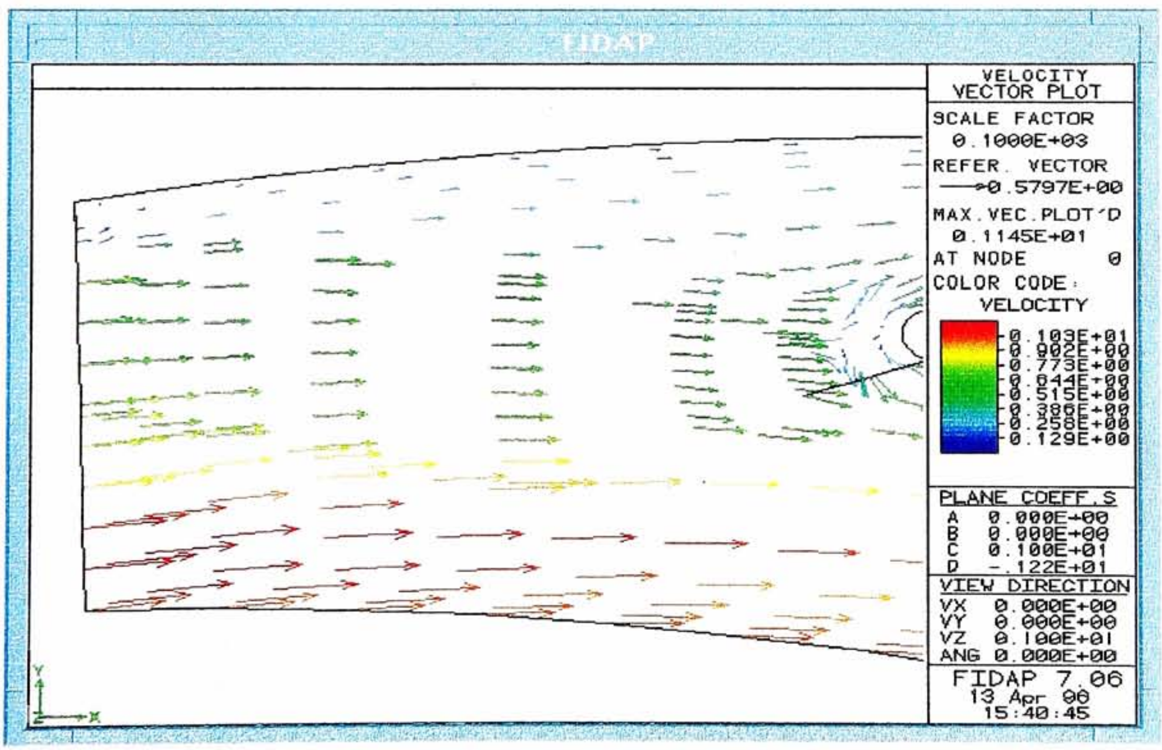


Figure 42 - Inlet Velocity on the Shroud Side (60% of Design Flow)

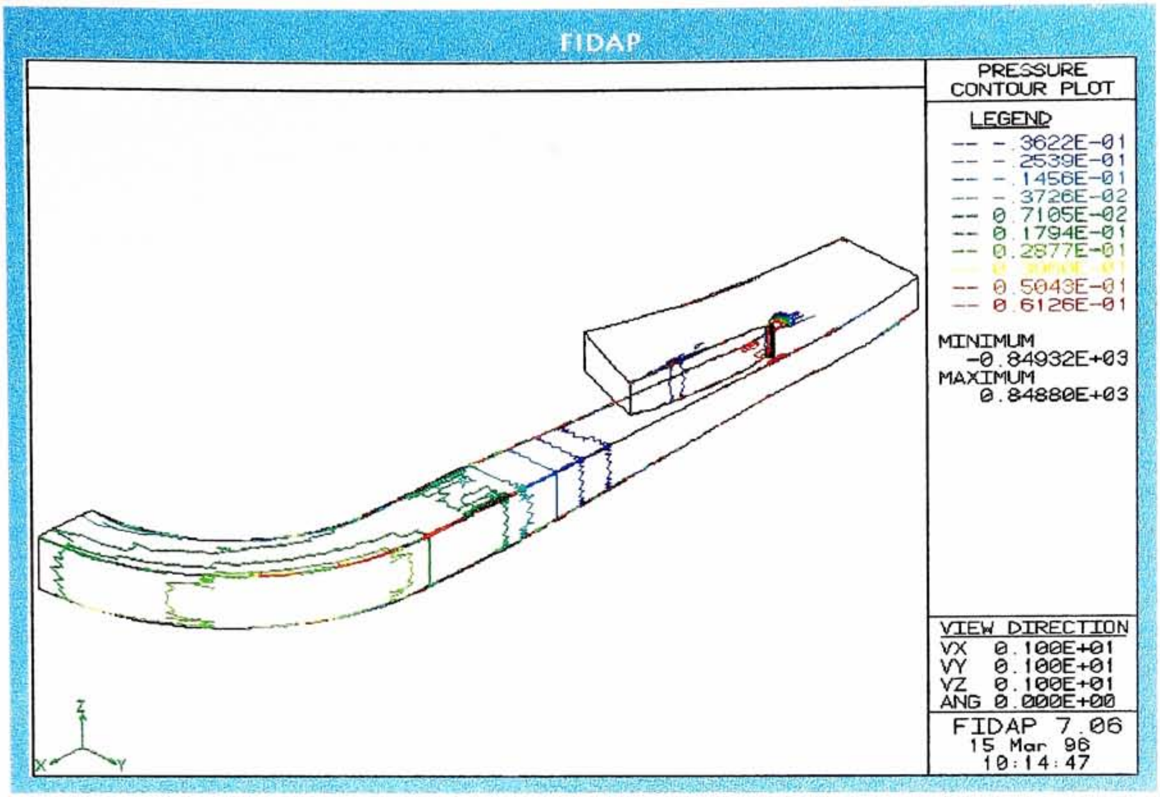


Figure 43 - Pressure Contour (60% of Design Flow)

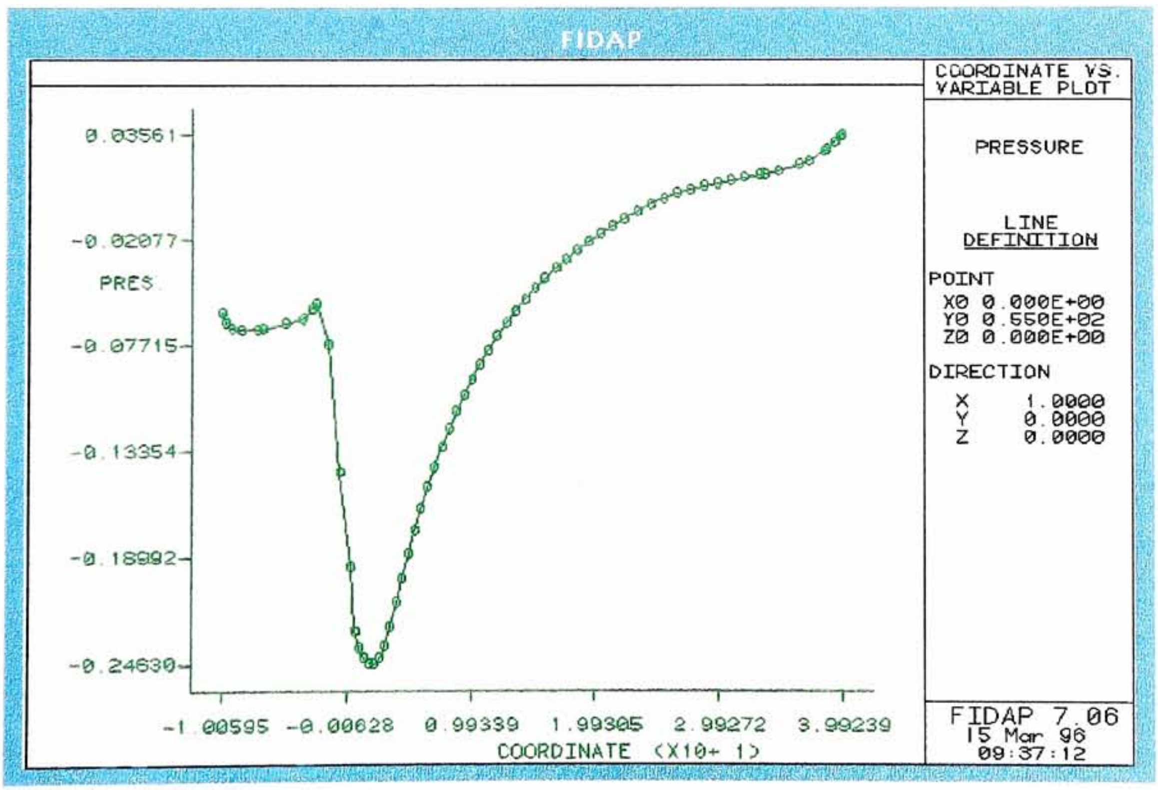


Figure 44 - Pressure Along Centerline (60% of Design Flow)

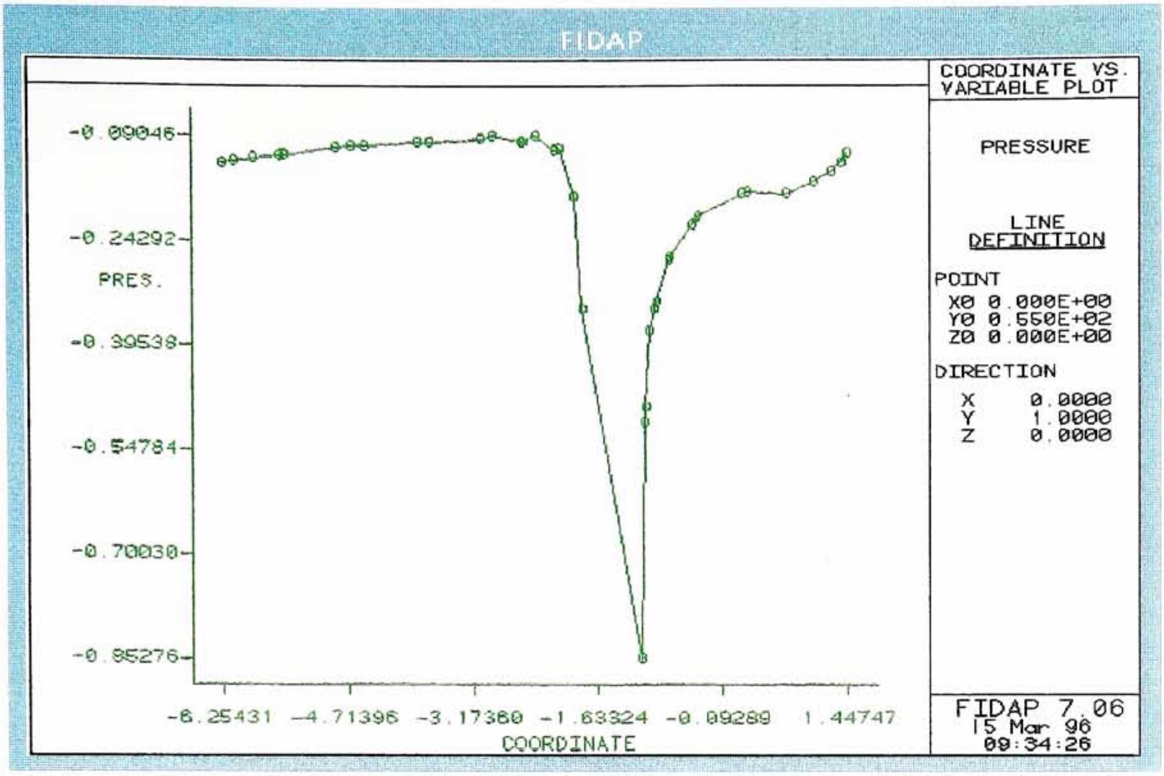


Figure 45 - Inlet Pressure (60% of Design Flow)

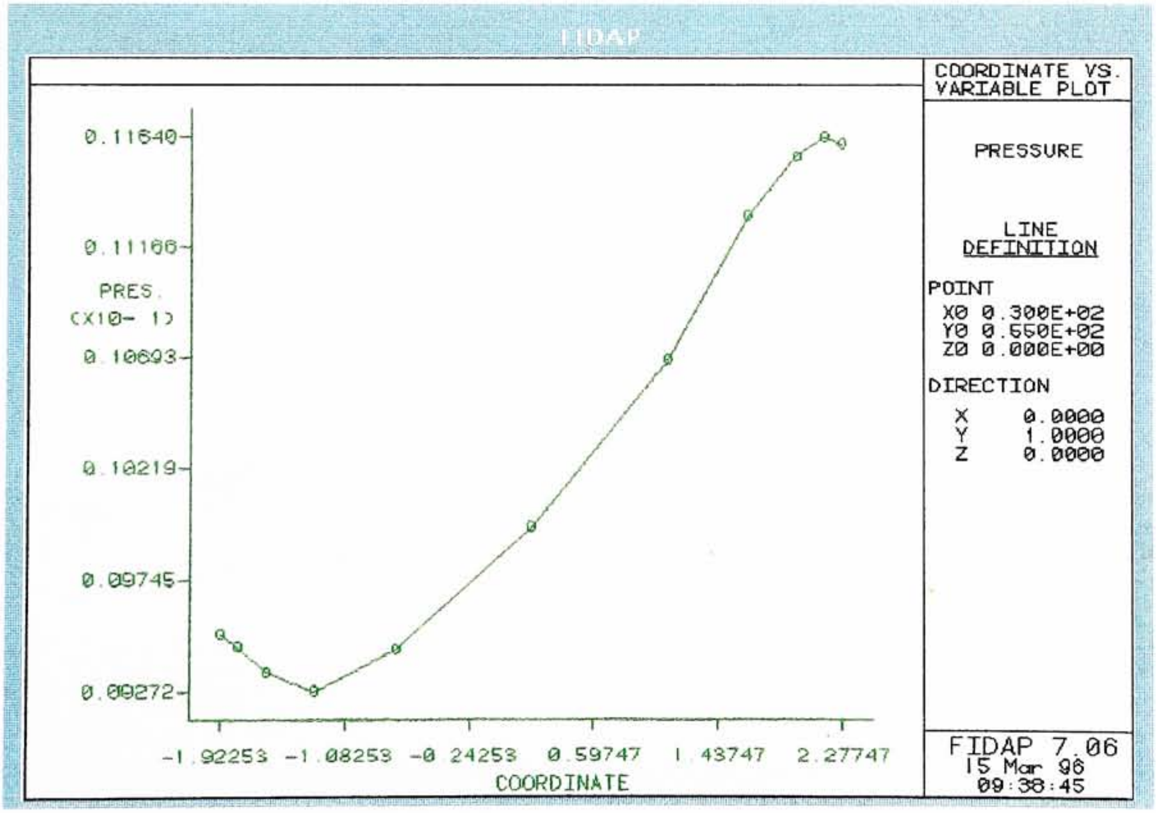


Figure 46 - Outlet Pressure (60% of Design Flow)

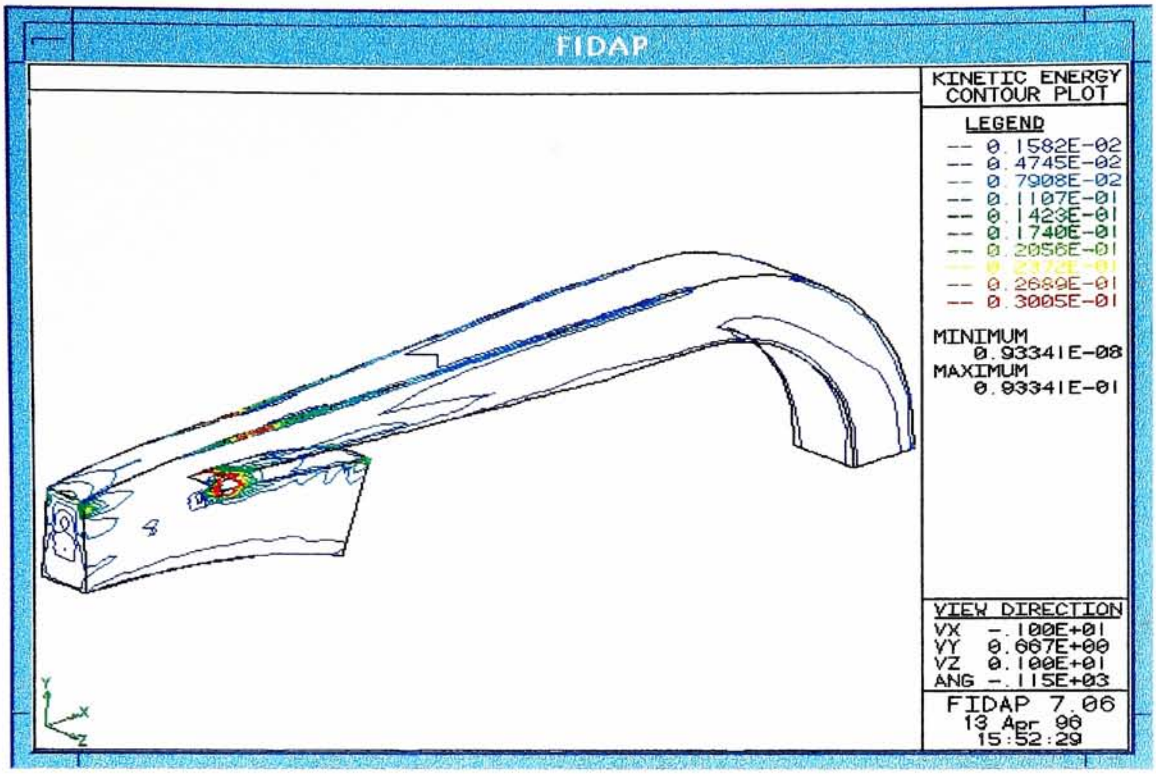


Figure 47 - Kinetic Energy Contour (60% of Design Flow)

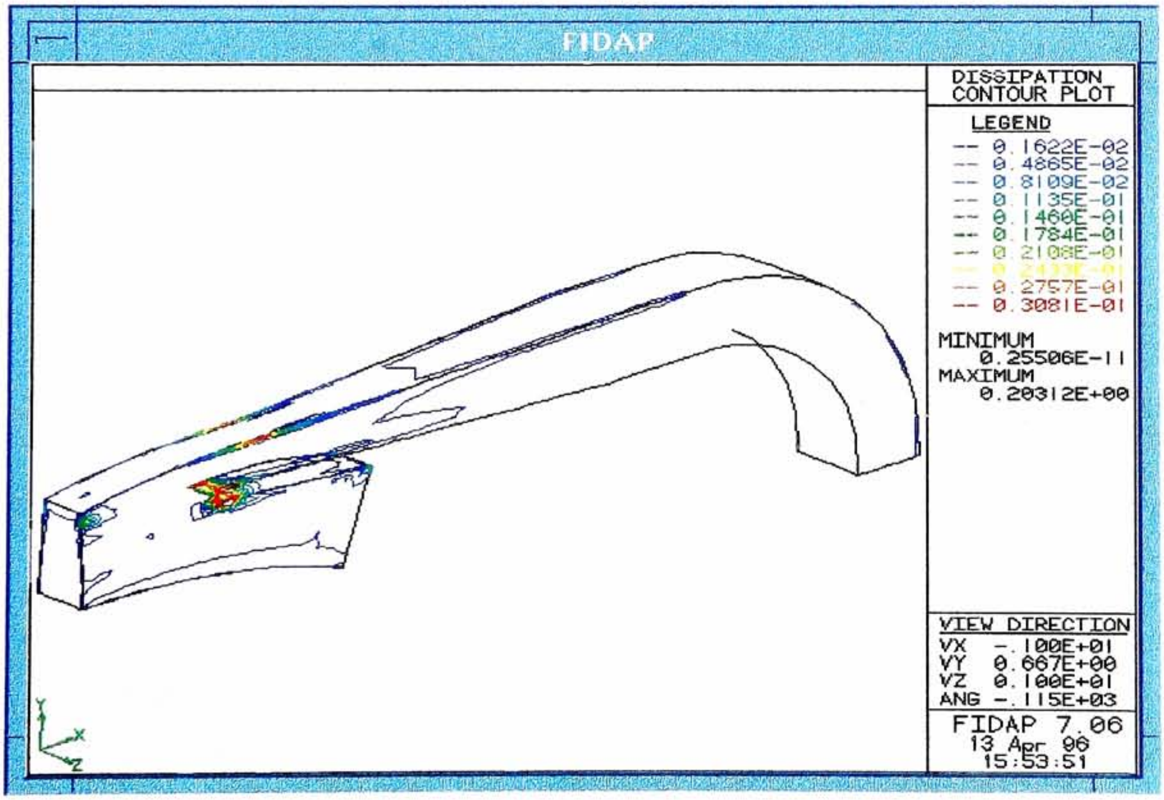


Figure 48 - Dissipation Contour (60% of Design Flow)

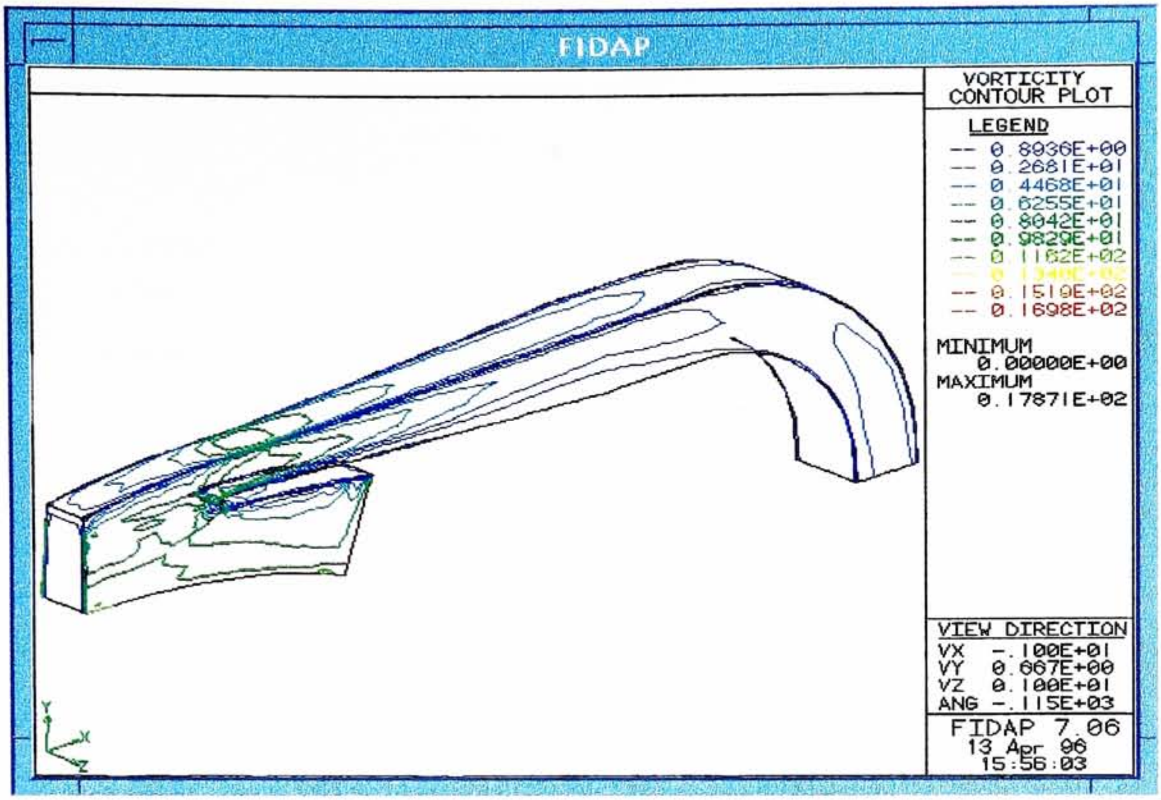


Figure 49 - Vorticity Contour (60% of Design Flow)

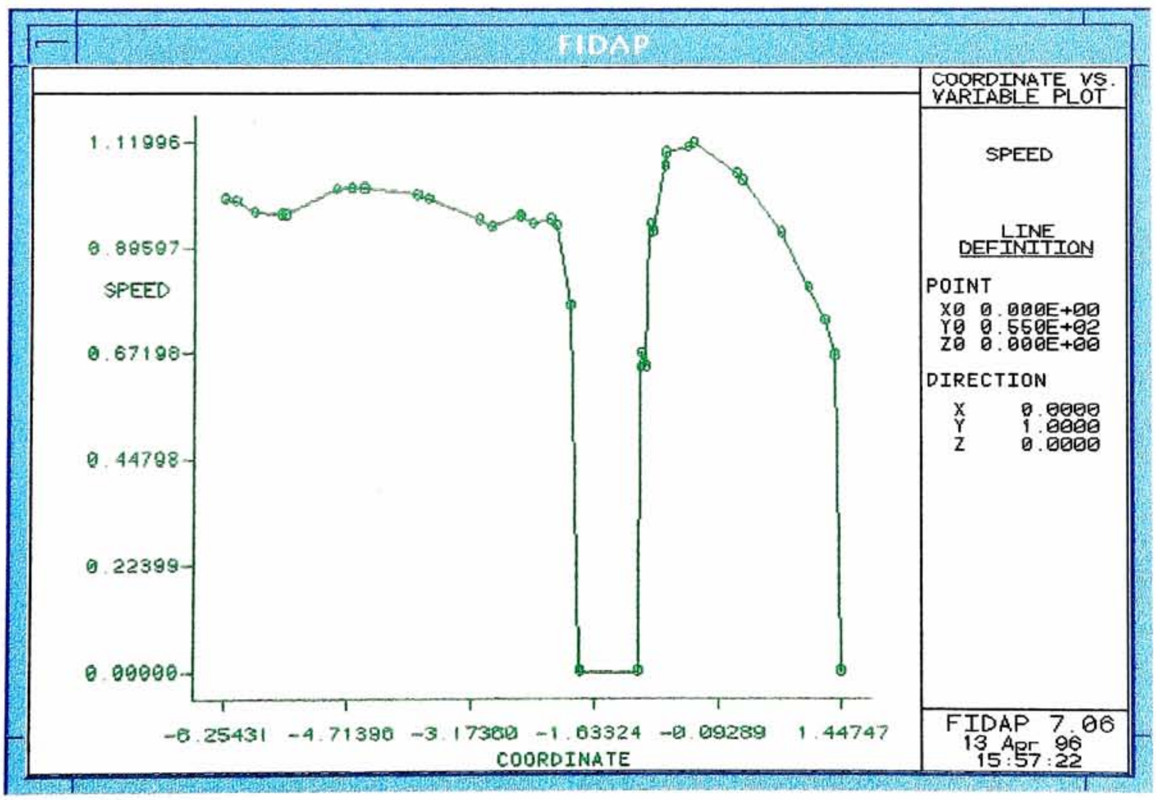


Figure 50 - Inlet Velocity Profile (60% of Design Flow)

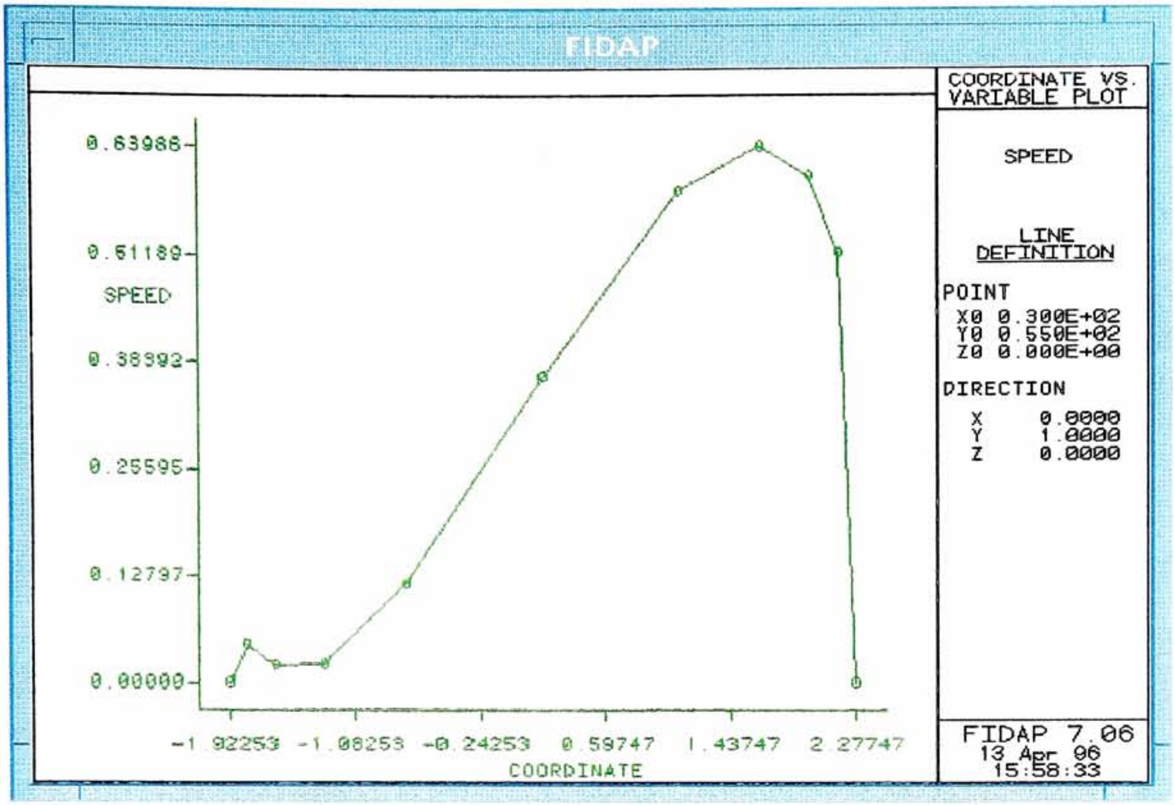


Figure 51 - Outlet Velocity Profile (60% of Design Flow)

7.3. 20% of Design Flow.

Now that the critical areas of flow separation are known and with the results of the design flow case available for comparison, the 20% of design flow case was analyzed. The objective was to study a case where large separation was expected to be found and compare these results to the ones that will be obtained later when fluid injection is used as a boundary layer control method.

The first plot is the velocity on the symmetry plane (Figure 52) which shows, as it happened in the 60% of design flow case, an area of flow separation at the diffuser's outlet near the bottom plane. The same effect, significantly increased, can be seen in the velocity vector plots on the shroud side plane (Figure 53) and on the bottom plane (Figure 54). The main difference with respect to the results obtained in the 60% of design flow case is that in this plane the flow starts to separate at the very beginning of the diffuser and that the amount of separation is larger. To get a better idea of where the flow separation was occurring, planes were cut through the diffuser to observe the velocity vector plots. The velocity vector plot on the shroud side plane is 0.07 mm away from the shroud side wall in the diffuser's inlet and 0.8988 mm in the diffuser's outlet. The velocity vector plot on the bottom plane is 0.07 mm away from the bottom plane in the diffuser's inlet and 0.8988 mm in the diffuser's outlet. In order to study this information more clearly, the perpendicular views of the velocity vector on the shroud side plane (Figure 55) and the bottom plane (Figure 56) were made. From these two plots it is easy to observe the area of reduced velocity but it is not easy to observe if there is flow separation. To verify that flow separation is occurring, two close-up views of the velocity vector plot on the shroud side (Figure 57) and on the bottom plane (Figure 58) were made From these two plots it can be seen a pocket of separated flow which begins at the bottom wall near the shroud side and then increases in size and intensity as flow separation builds up and diffuser stall occurs.

As it was shown in the design flow case, flow separation also was found in the shroud side of the vaneless region (Figure 59). Secondary flow effects are probably the responsible of the flow separation. This has a big impact in the diffuser's performance since the fluid is not coming into the diffuser uniformly which affects the diffuser's pressure recovery characteristics. The pressure contour plot (Figure 60) and the pressure along the centerline (Figure 61) indicate a relatively uniform conversion of dynamic head to static pressure as the diffuser is traversed in the direction of flow. Using the pressure line plots from the bottom of the diffuser to the top, at the diffuser inlet (Figure 62) and outlet (Figure 63), the pressure recovery coefficient was calculated to be 0.50. The value of the inlet pressure is affected by the separation in the vaneless region and the value of the outlet pressure is affected by the flow separation in the bottom plane of the diffuser.

The kinetic energy (Figure 64), dissipation (Figure 65), and vorticity (Figure 66) contour plots are included for flow verification. The majority of the kinetic energy is generated at the top and bottom planes near the shroud side wall, with a corresponding amount of dissipation in the same area. The vorticity, which is an indication of the level of viscosity present in the fluid at a particular location, is higher on the top surface. The velocity profiles that were graphed at positions near the diffuser inlet (Figure 67) and outlet (Figure 68) on the symmetry plane are typical of turbulent flow in a diffuser. The inlet velocity profile shows the flow separation that occurs in the diffuser's vaneless region and the outlet velocity profile shows the flow separation that is present in the diffuser's bottom plane near the shroud side.

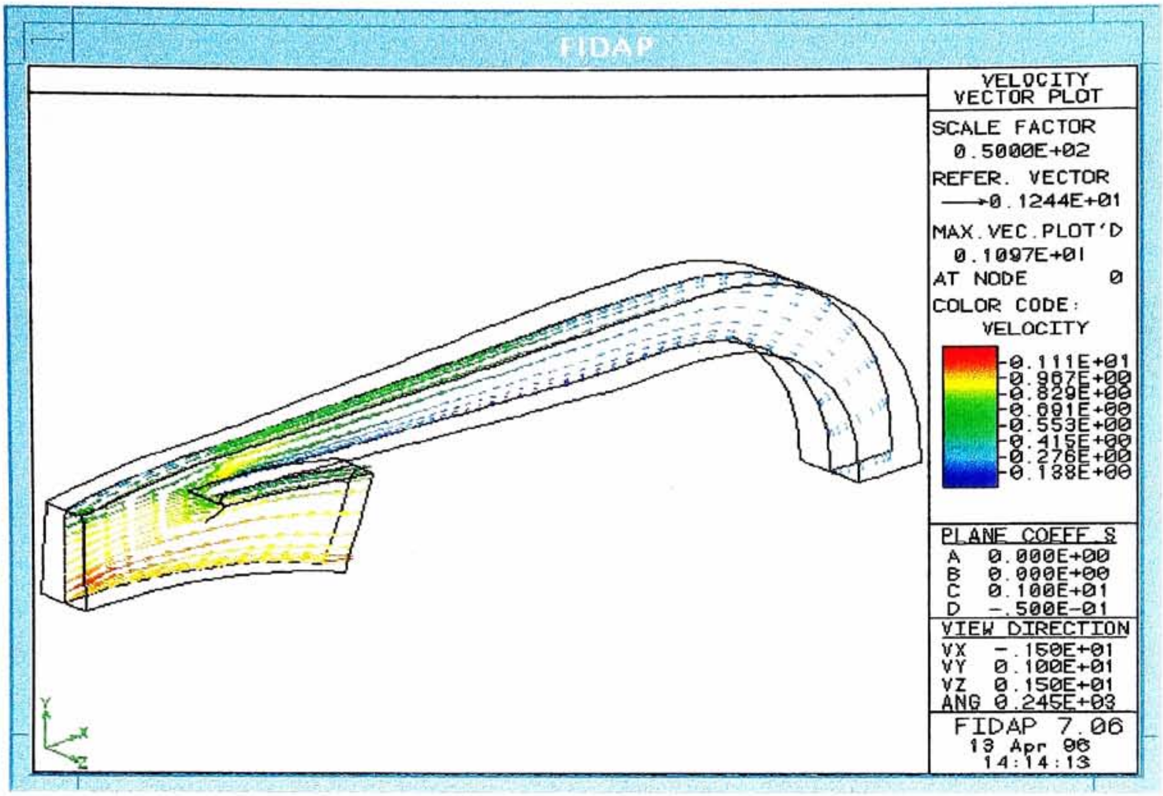


Figure 52 - Velocity on Symmetry Plane (20% of Design Flow)

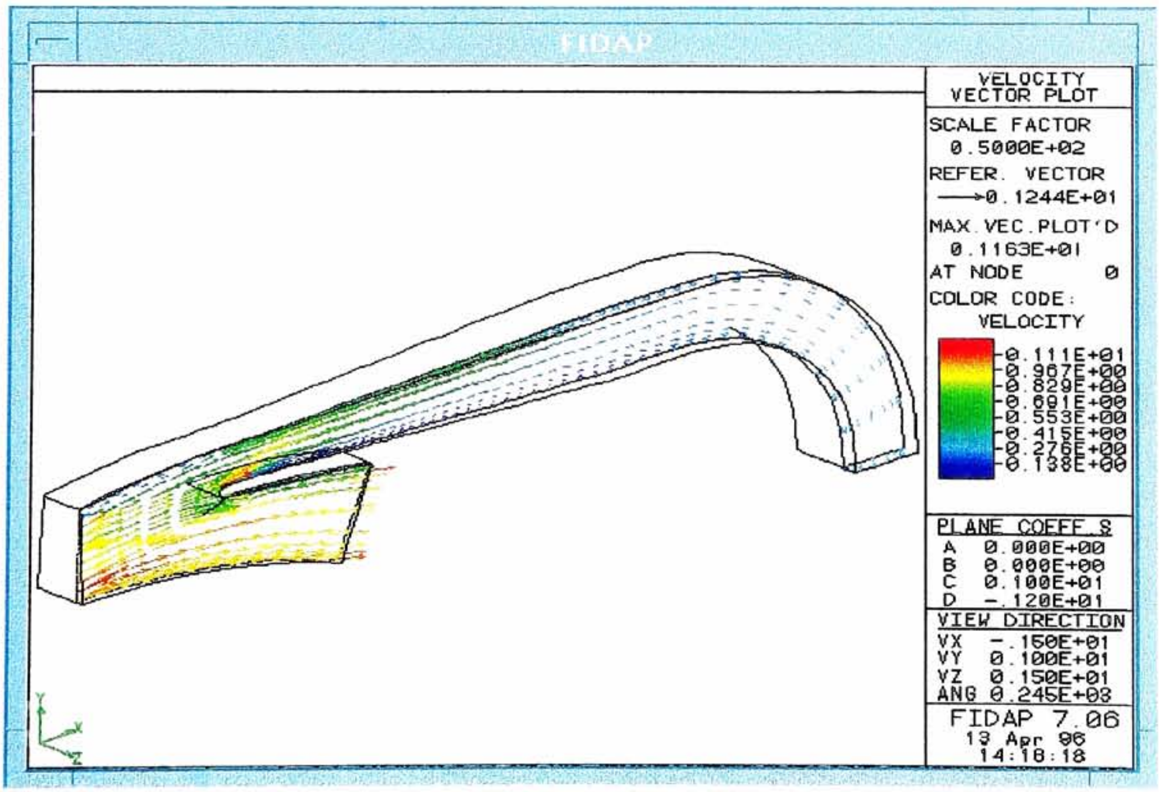


Figure 53 - Velocity on Shroud Side Plane (20% of Design Flow)

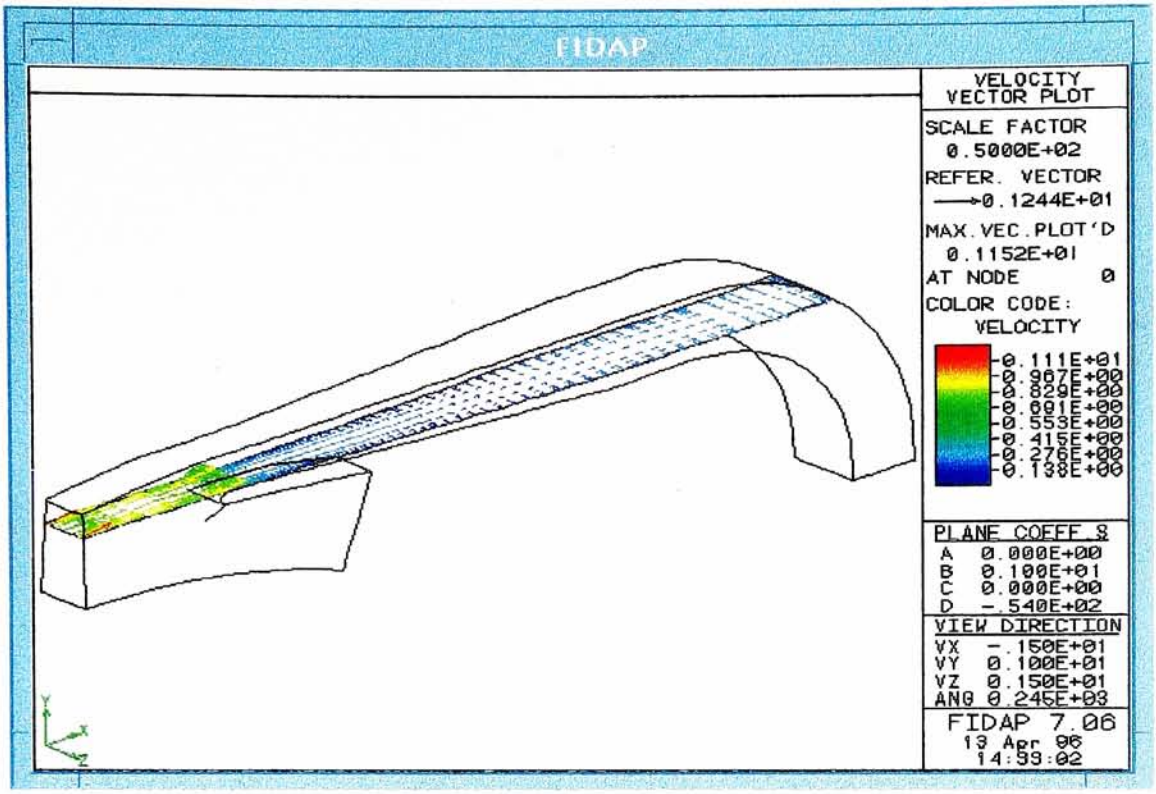


Figure 54 - Velocity on Bottom Plane (20% of Design Flow)

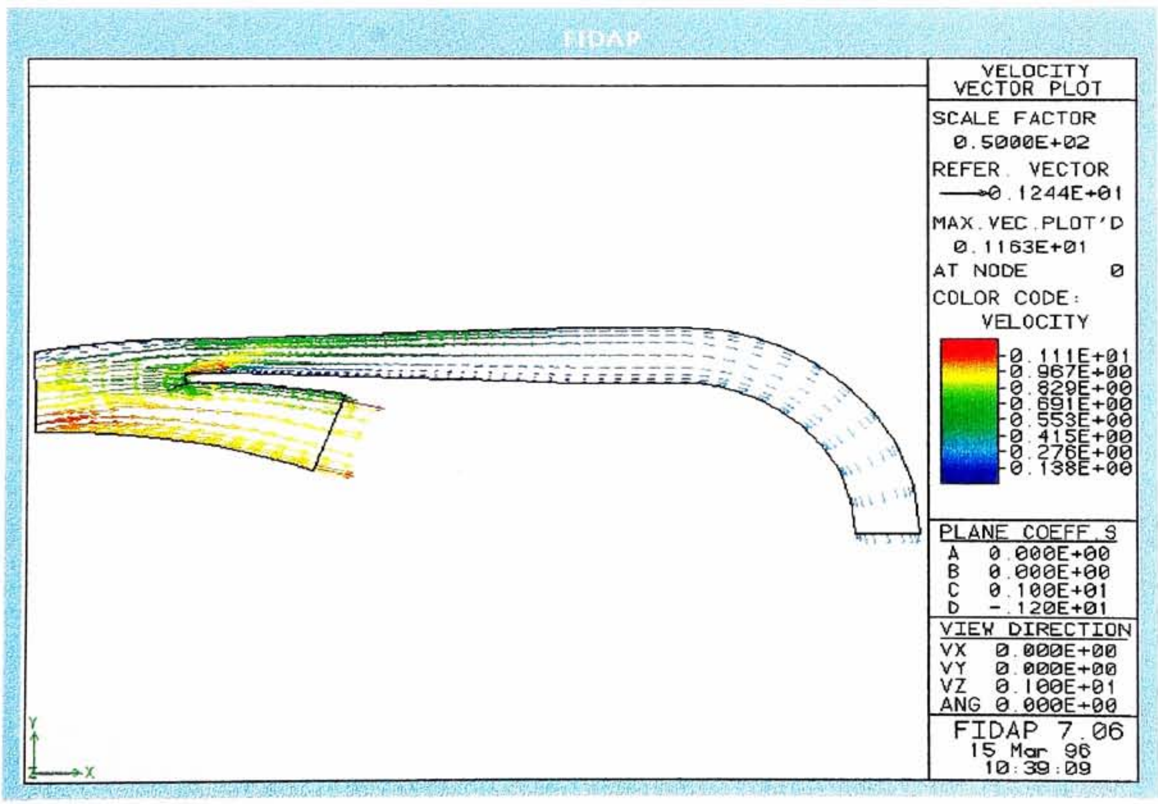


Figure 55 - 2-D View of Velocity on Shroud Side (20% of Design Flow)

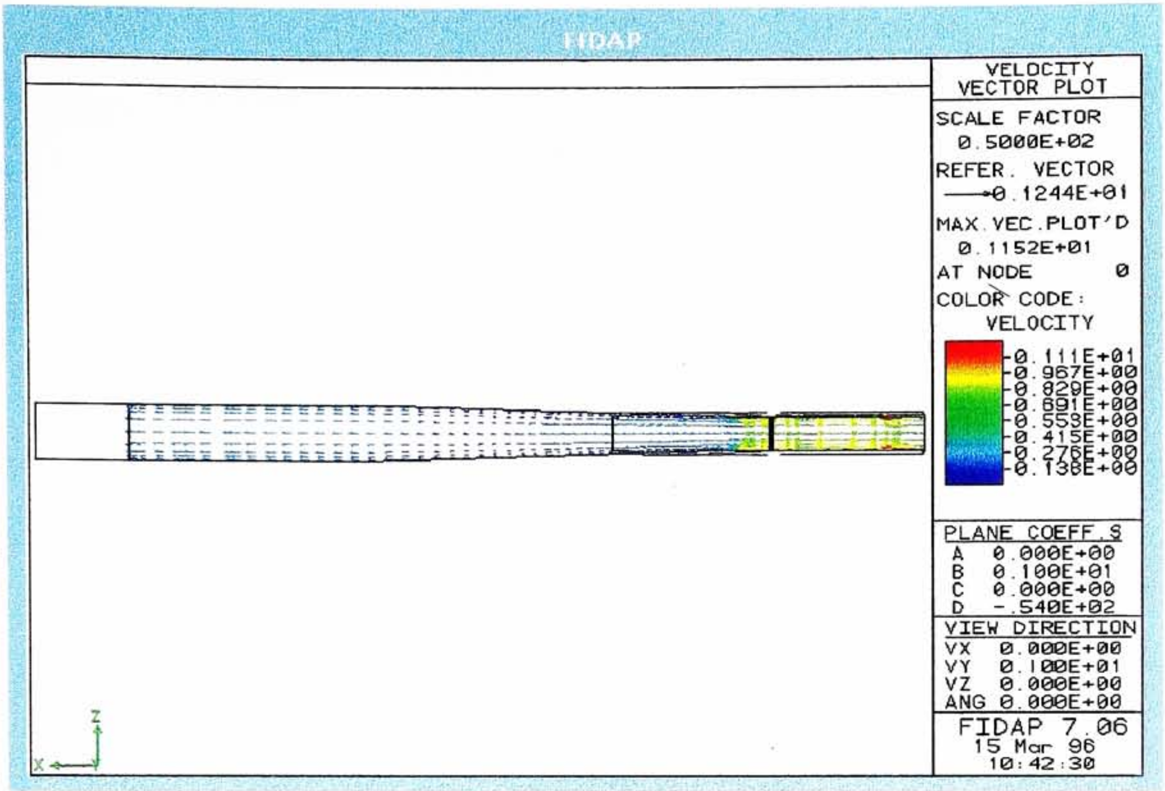


Figure 56 - 2-D View of Velocity on Bottom (20% of Design Flow)

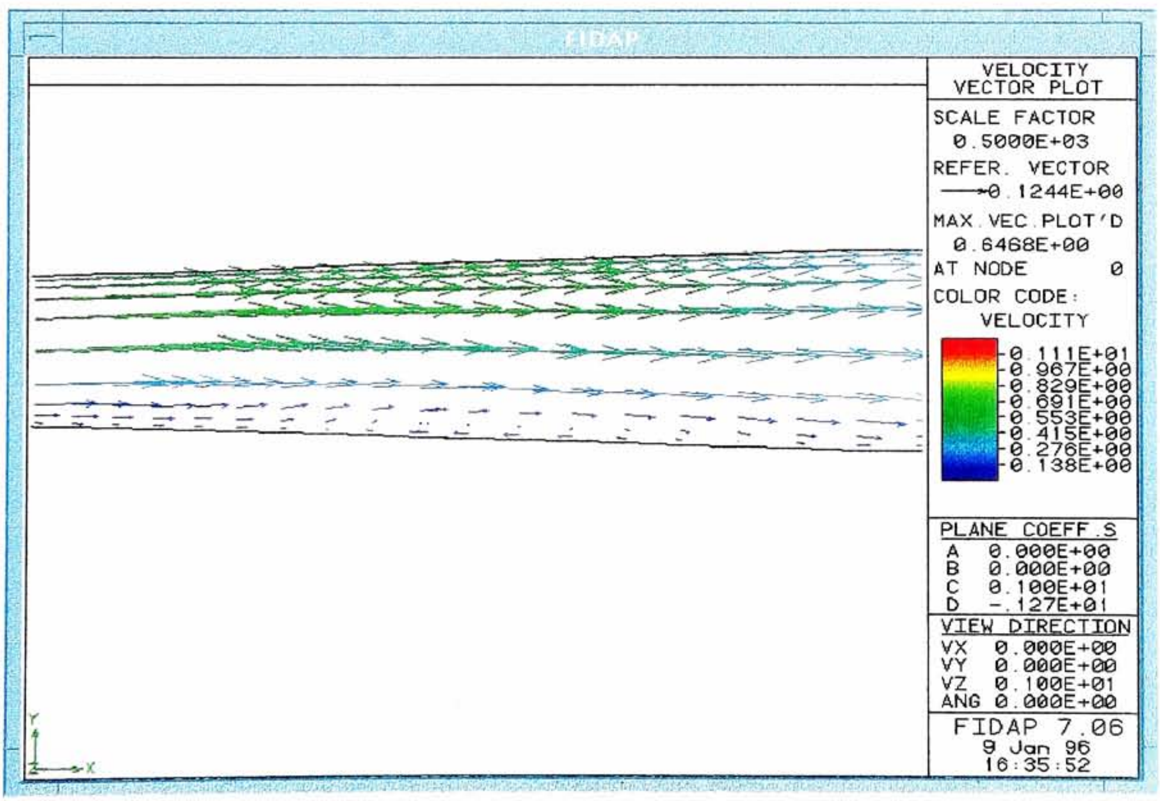


Figure 57 - Velocity at Outlet on Shroud Side (20% of Design Flow)

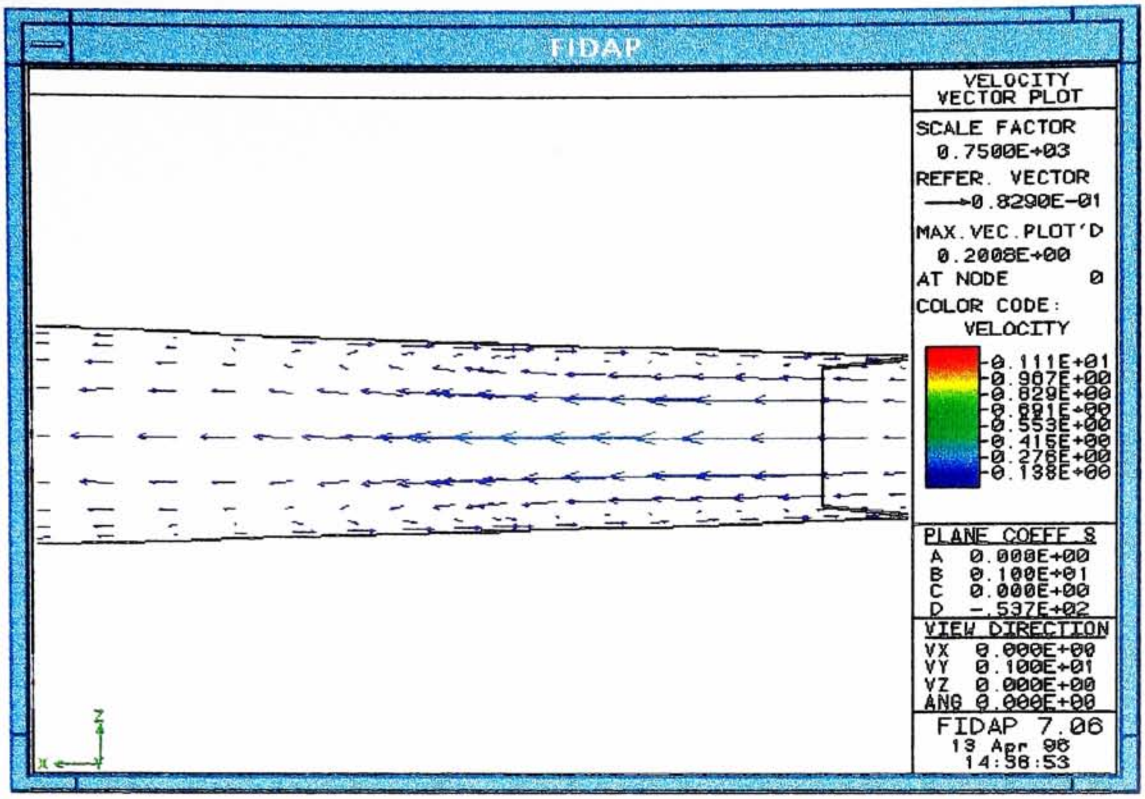


Figure 58 - Velocity at Outlet on Bottom (20% of Design Flow)

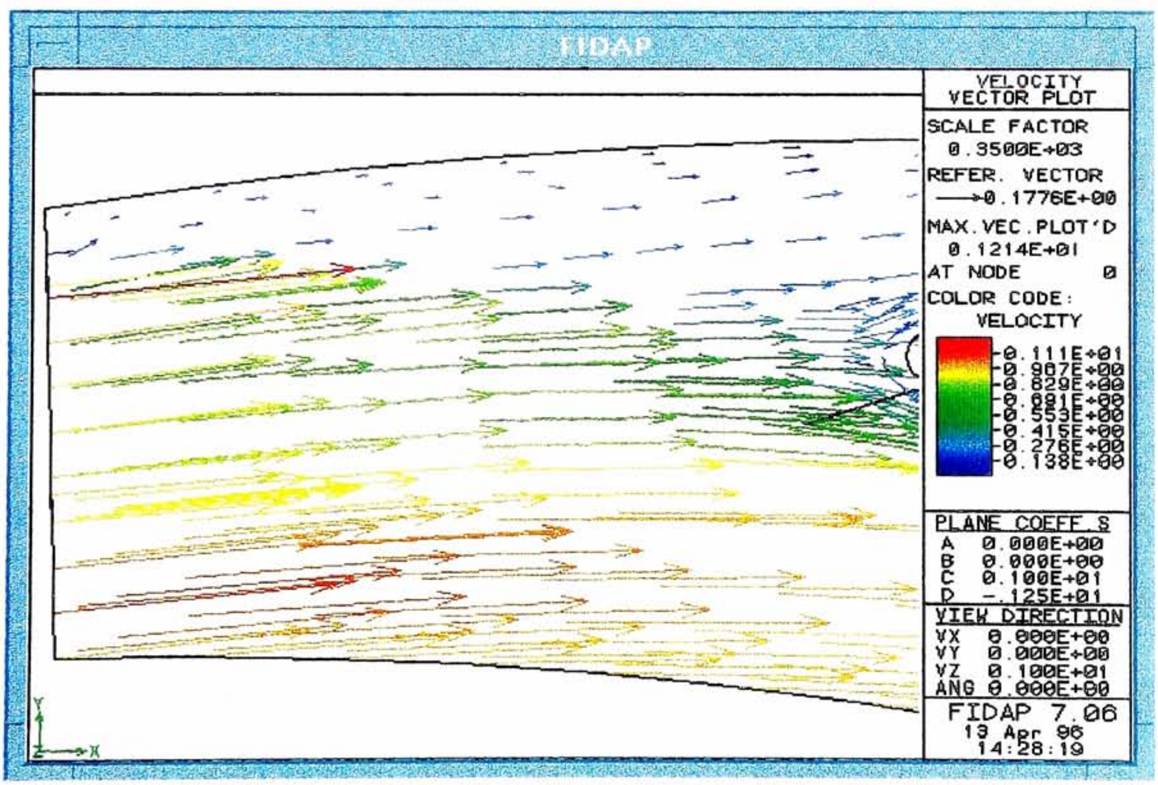


Figure 59 - Inlet Velocity on the Shroud Side (20% of Design Flow)

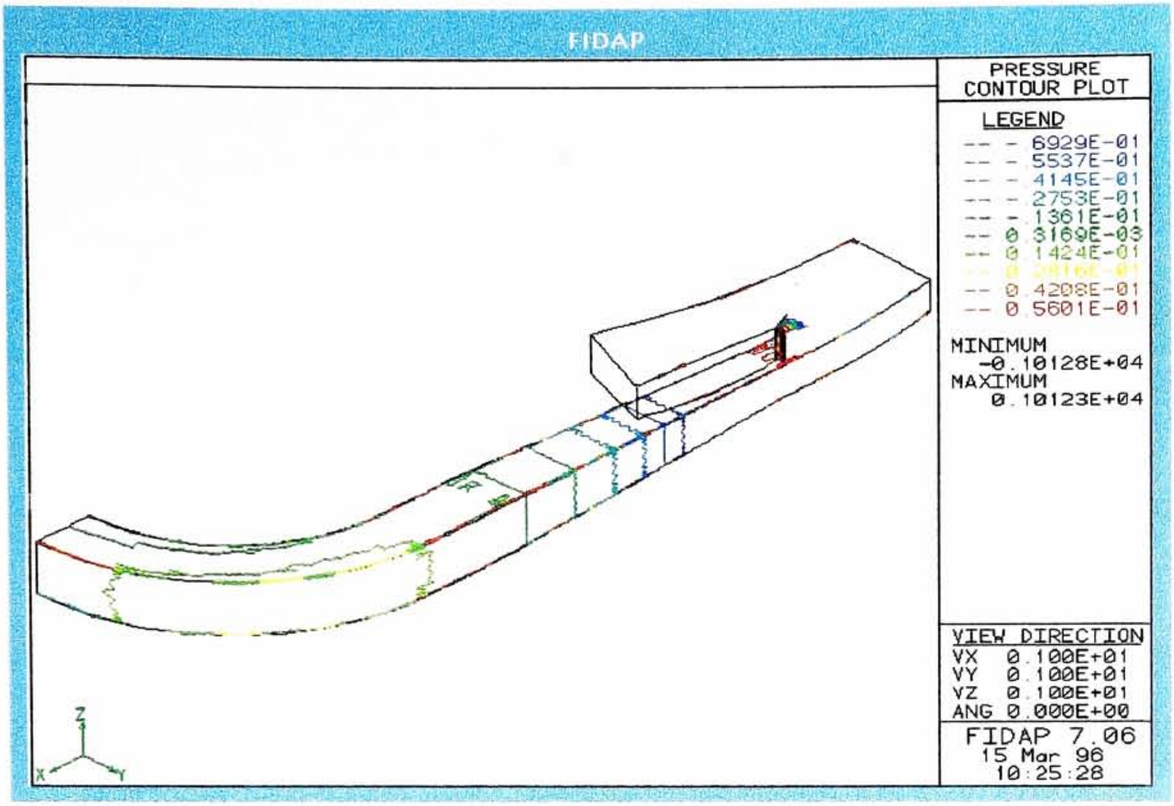


Figure 60 - Pressure Contour (20% of Design Flow)

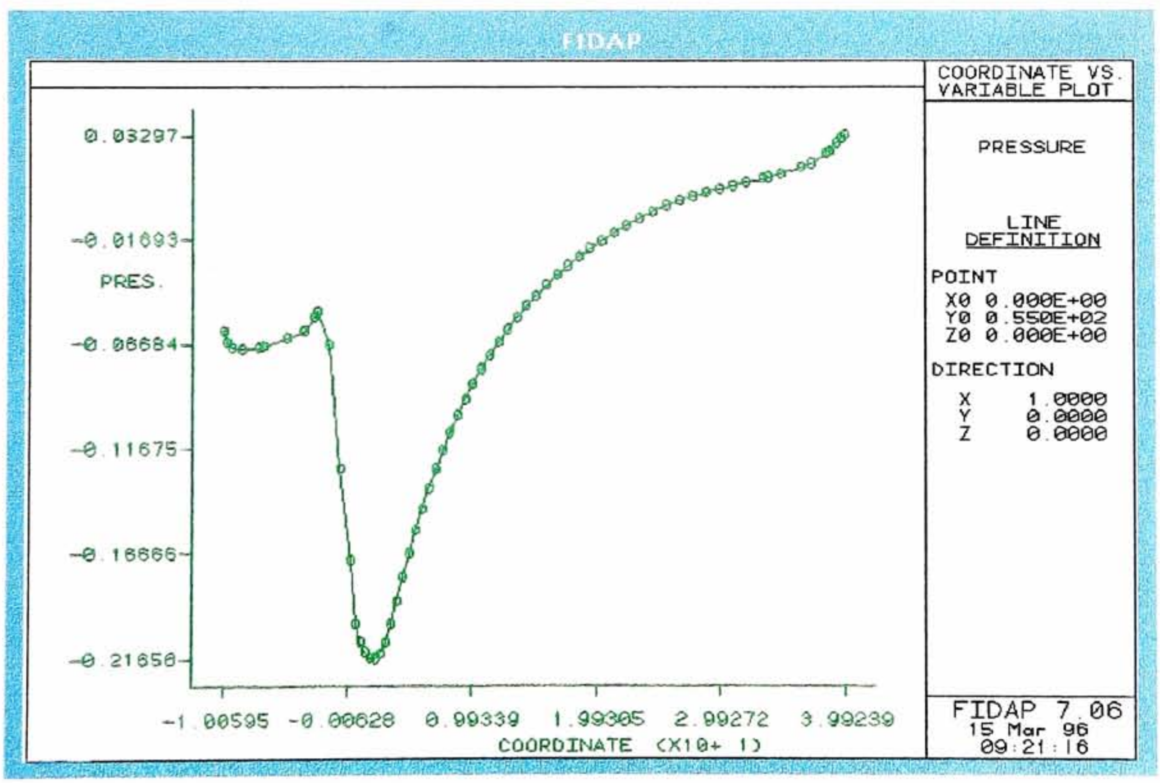


Figure 61 - Pressure Along Centerline (20% of Design Flow)

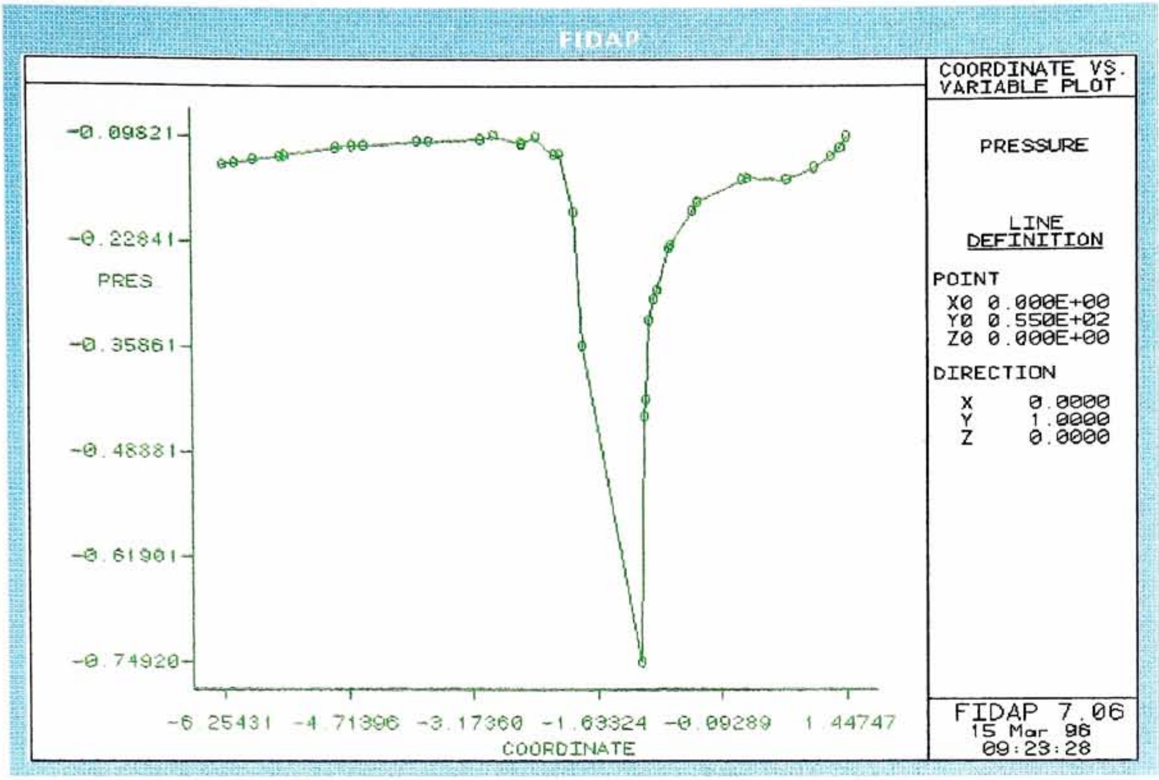


Figure 62 - Inlet Pressure (20% of Design Flow)

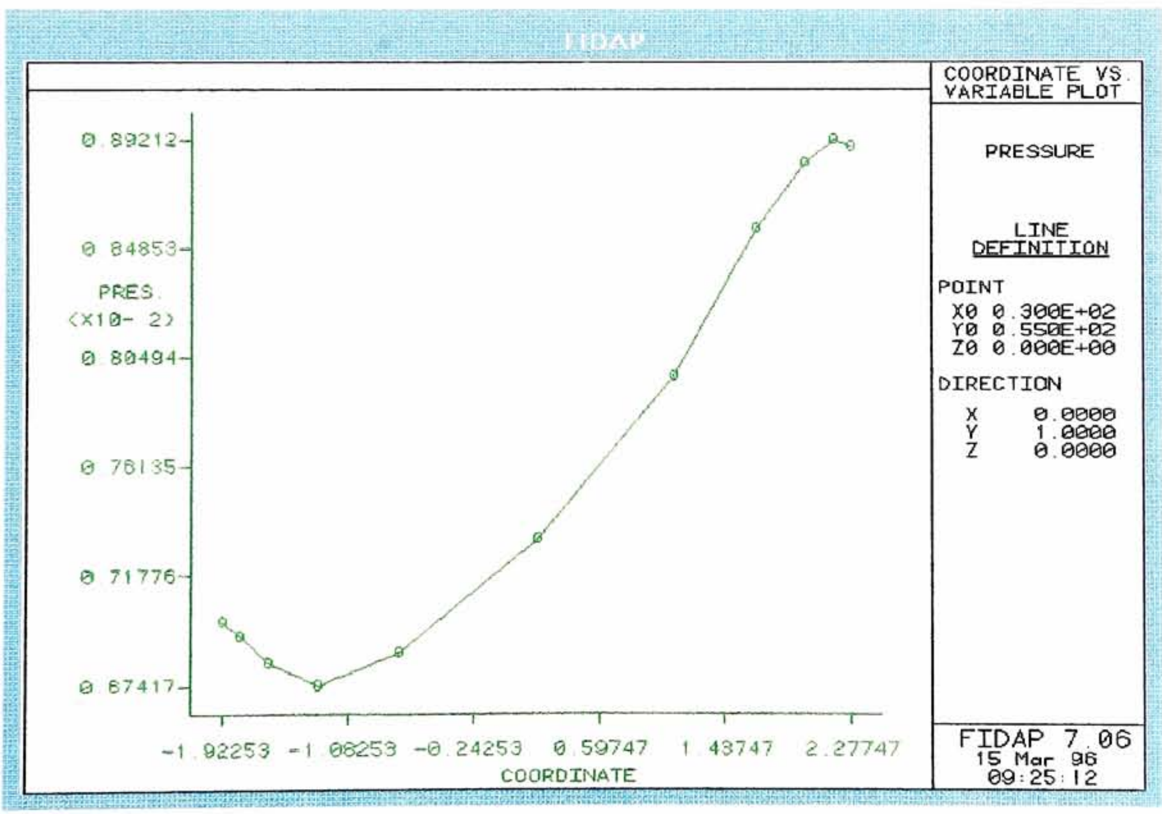


Figure 63 - Outlet Pressure (20% of Design Flow)

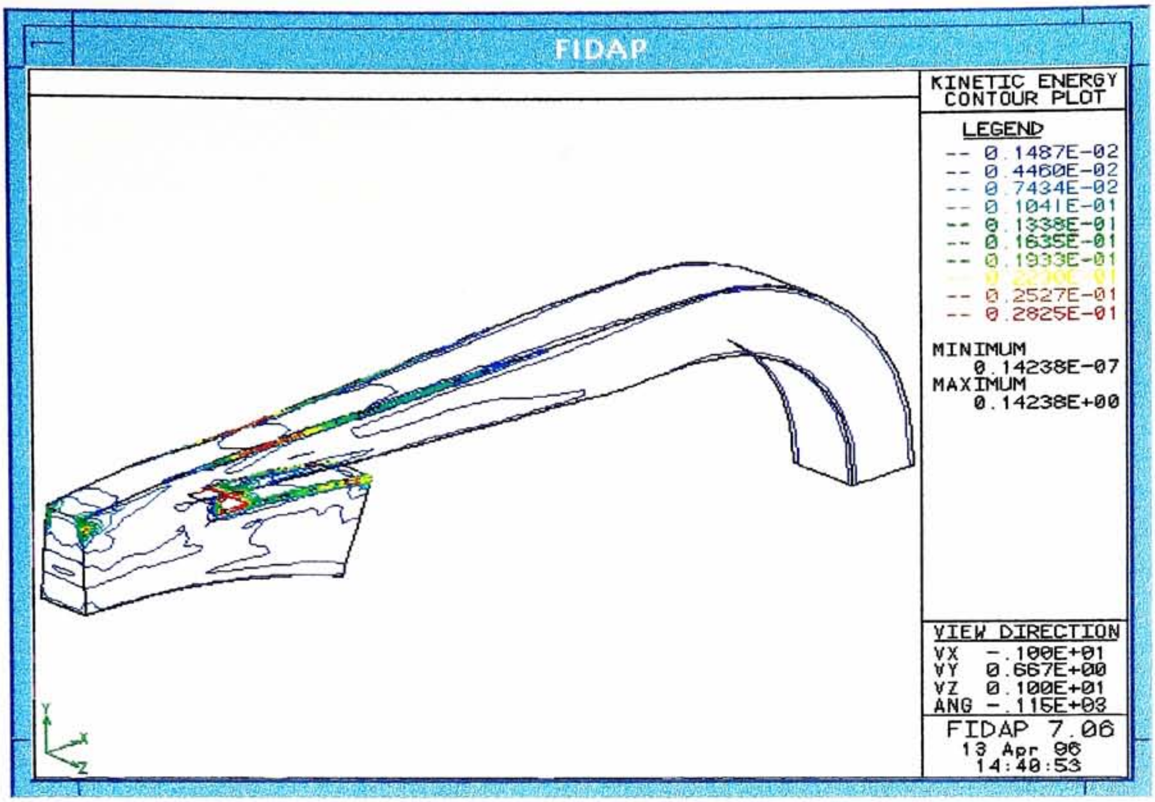


Figure 64 - Kinetic Energy Contour (20% of Design Flow)

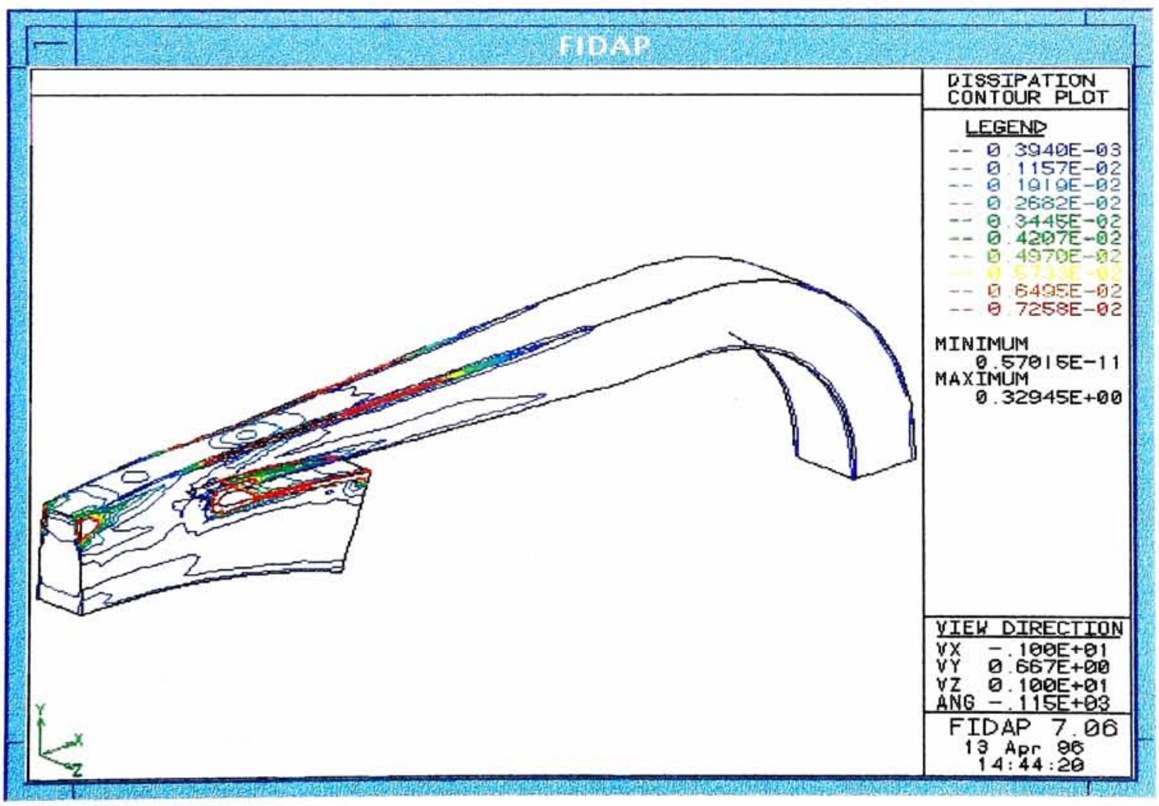


Figure 65 - Dissipation Contour (20% of Design Flow)

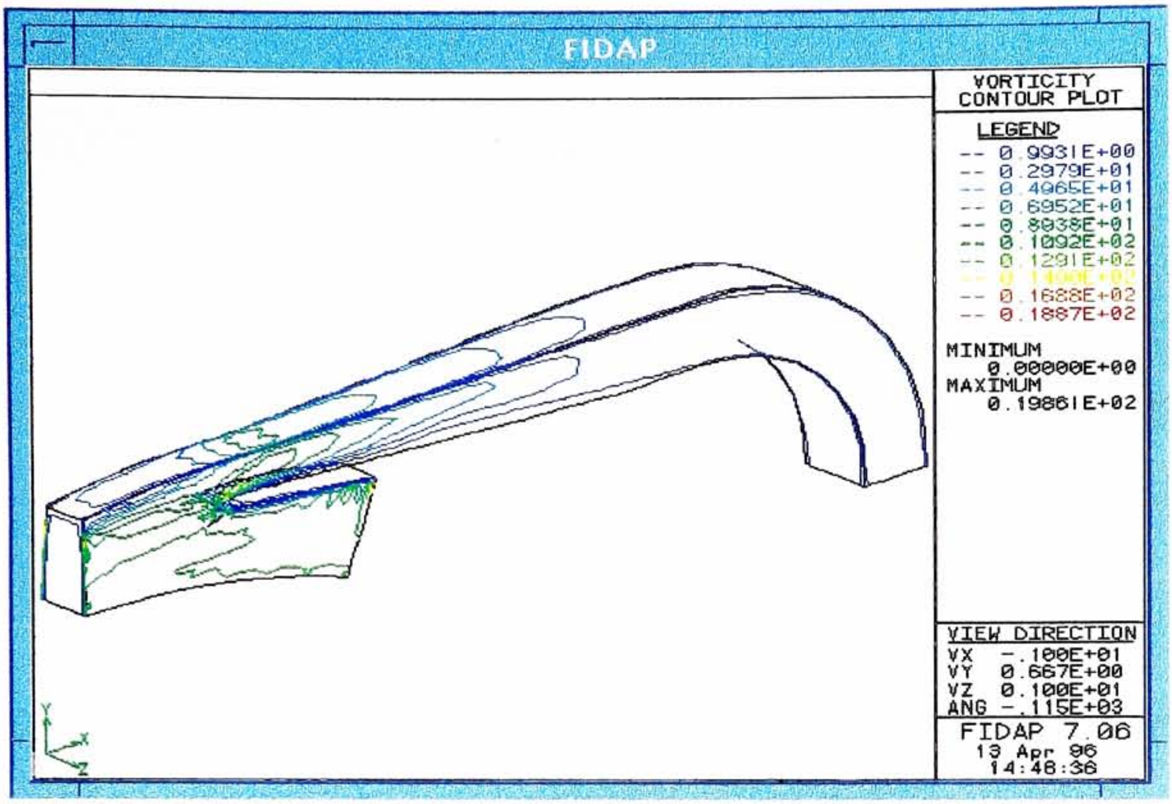


Figure 66 - Vorticity Contour (20% of Design Flow)

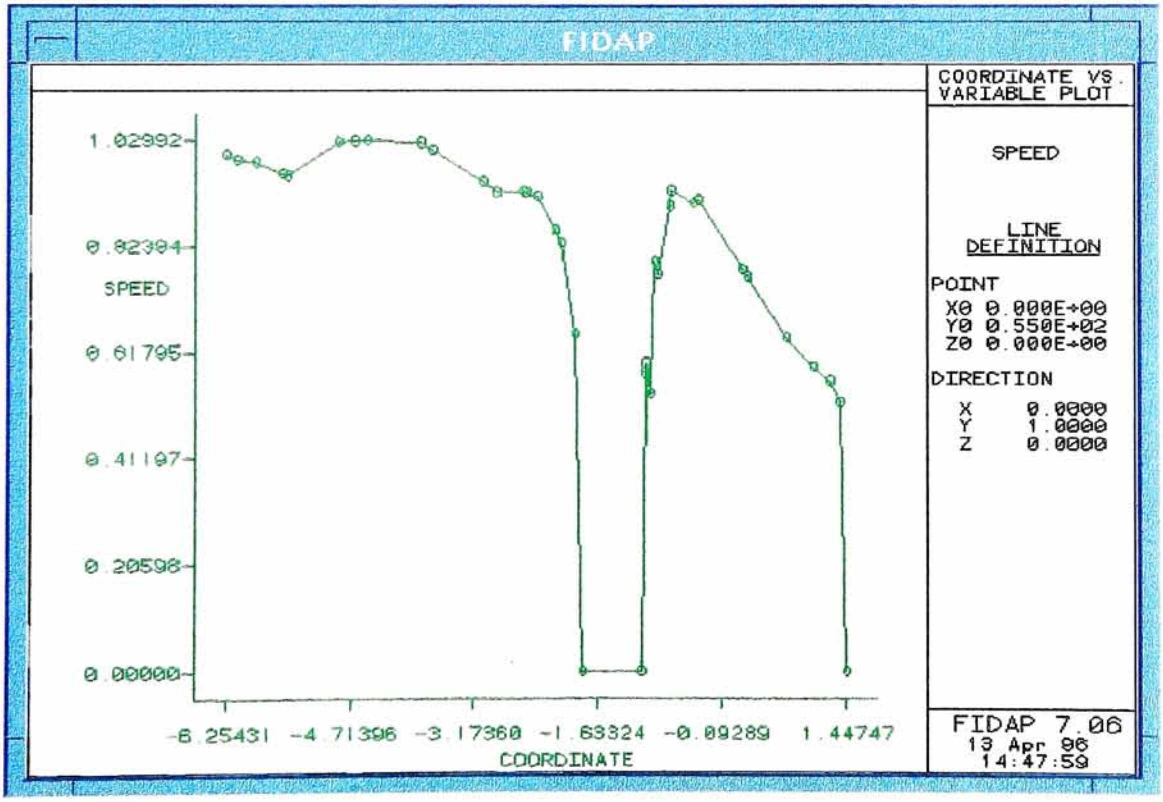


Fig 67 - Inlet Velocity Profile (20% of Design Flow)

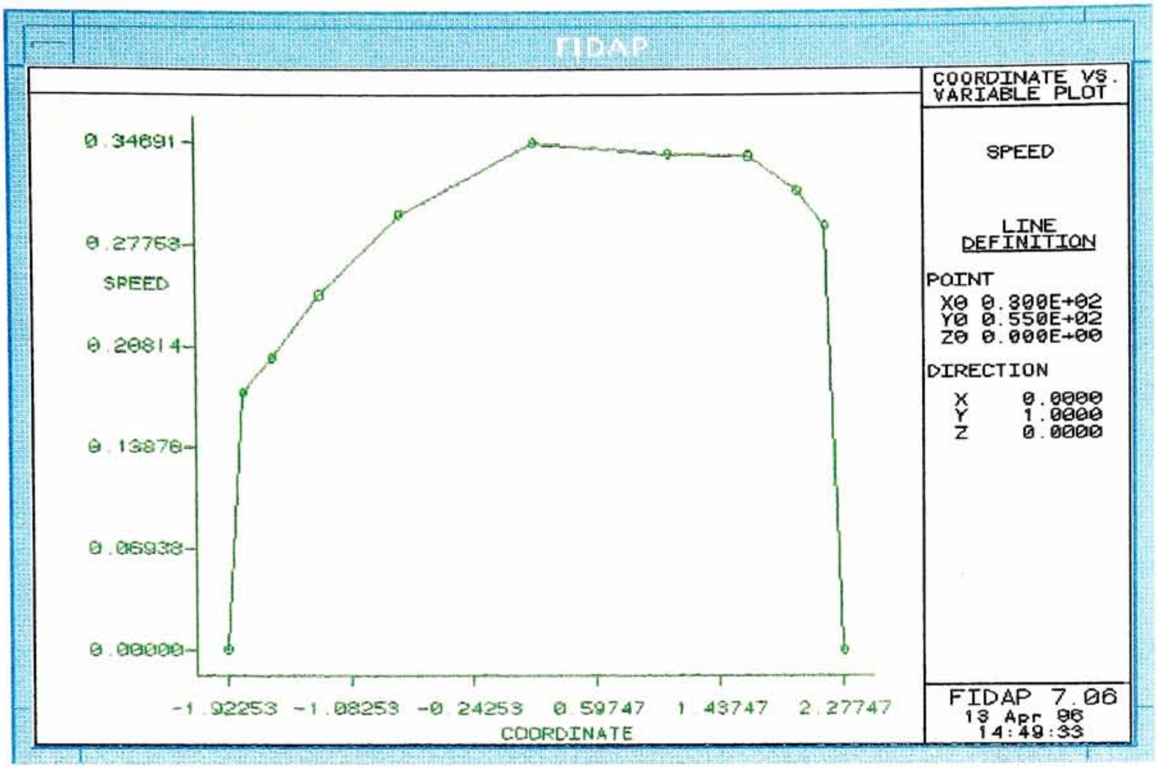


Fig 68 - Outlet Velocity Profile (20% of Design Flow)

7.4. Fluid Injection.

To decrease the separation that was observed when decreasing the flow rate, fluid injection was applied through a series of slits located on the bottom plane of the diffuser's throat and inlet section., as shown in Figure 15, with each slit being 2 mm. in length along the diffuser's width. These fluid injection slits are meant to increase the momentum of the decelerating particles before the boundary layer is able to depart from the wall.

7.4.1. 60%-3% Flow Case.

The injection rate of 3% of the inlet mass flow through the six slits at an angle of 35 degrees, relative to the diffuser centerline, resulted in the application of a horizontal component of 0.0079 and a vertical component of 0.005459 as boundary conditions at the fluid injection slits (Refer to Appendix A for the calculations).

The velocity vector plot on the symmetry plane (Figure 69) shows a uniform flow and it can be seen that there is no separation. The same phenomenon is observed in the shroud side plane (Figure 70) and on the bottom plane (Figure 71), which are the same planes used before to observe the area of maximum flow separation. The perpendicular views of the shroud side plane (Figure 72) and bottom plane (Figure 75) also show no signs of flow separation. The effect of the injected fluid can be seen on the close ups of the shroud side. The first one (Figure 73) shows how the fluid is being injected into the diffuser and accelerates the particles that are starting to slow down near the wall. It is important to notice the effect of each slit on the fluid: the first two slits don't seem to be able to accelerate the fluid particles enough but once the fluid reaches the third slit, it is clear that its velocity increases. The second close up (Figure 74) shows the behavior of the fluid in the diffuser and once again it can be seen that there is no flow separation anywhere in the diffuser. The same behavior can be observed in the perpendicular view of the velocity vector on the bottom plane (Figure 75). A close up of this case was made to verify these results (Figure 76).

As it was shown in the 60% of the design flow case, flow separation also was found in the shroud side of the vaneless region (Figure 77). Secondary flow effects are probably the responsible for the creation of this area of flow separation. The pressure contour plot (Figure 78) and the pressure along the centerline (Figure 79) indicate a relatively uniform conversion of dynamic head to static pressure as the diffuser is traversed in the direction of flow. Using the pressure line plots from the bottom of the diffuser to the top, at the diffuser inlet (Figure 80) and outlet (Figure 81), the pressure recovery coefficient was calculated to be 0.6776. From these results it can be seen how fluid injection improves the performance of the diffuser. For the 60% case, the pressure recovery coefficient , Cp, was calculated to be 0.56 and when 3% of the mass flow rate is injected, the pressure recovery coefficient comes out to be 0.6776 which is a significant improvement.

The kinetic energy (Figure 82), dissipation (Figure 83), and vorticity (Figure 84) contour plots are included for flow verification. The majority of the kinetic energy is generated at the diffuser's entrance region on both the top and bottom planes near the shroud side wall, with a corresponding amount of dissipation in the same area. The vorticity, which is an indication of the level of viscosity present in the fluid at a particular location, shows also this behavior. This could be caused by the injection of fluid in this part of the diffuser. The velocity profiles that were graphed at positions near the diffuser inlet (Figure 85) and outlet (Figure 86) of the diffuser on the symmetry plane and are typical of turbulent flow in a diffuser. The inlet velocity profile shows the flow separation that occurs in the entrance to the vaneless section and the outlet velocity profile shows the significant reduction in the flow speed that is present in the diffuser's bottom plane near the shroud side.

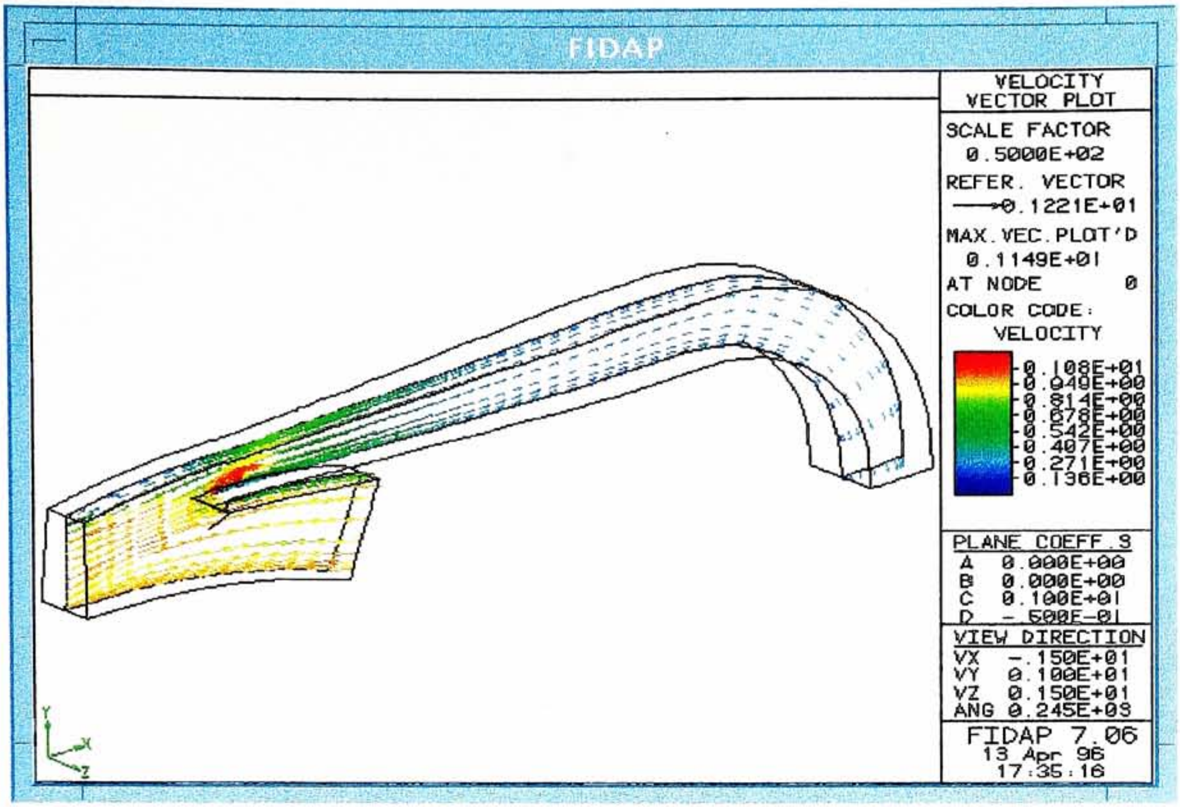


Figure 69 - Velocity on Symmetry Plane (60% - 3%)

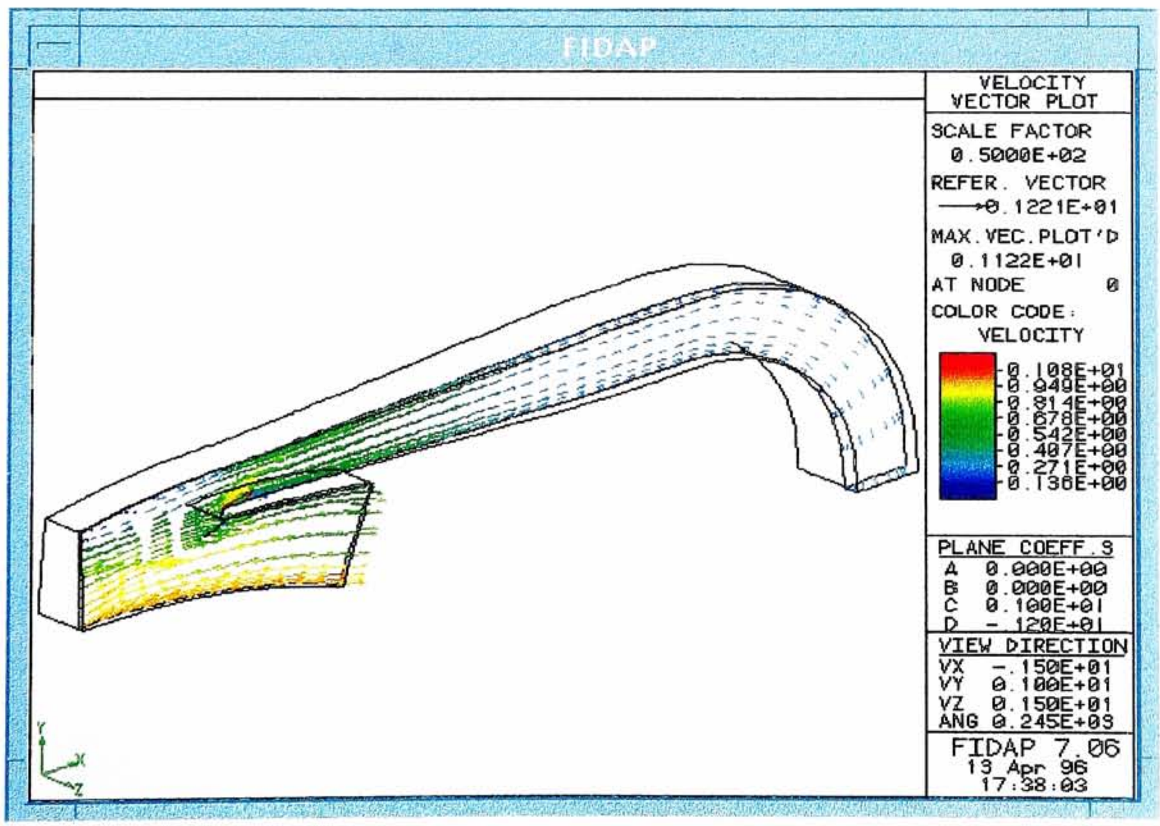


Figure 70 - Velocity on Shroud Side Plane (60% - 3%)

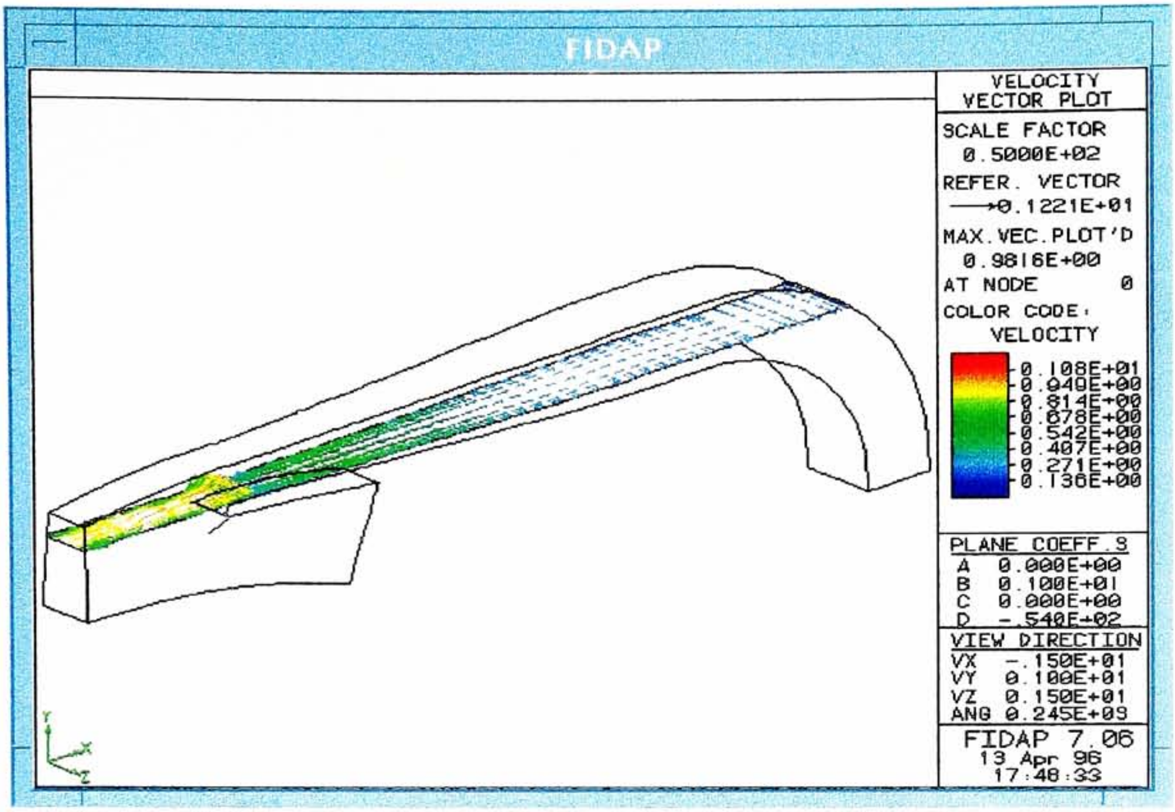


Figure 71 - Velocity on Bottom Plane (60% - 3%)

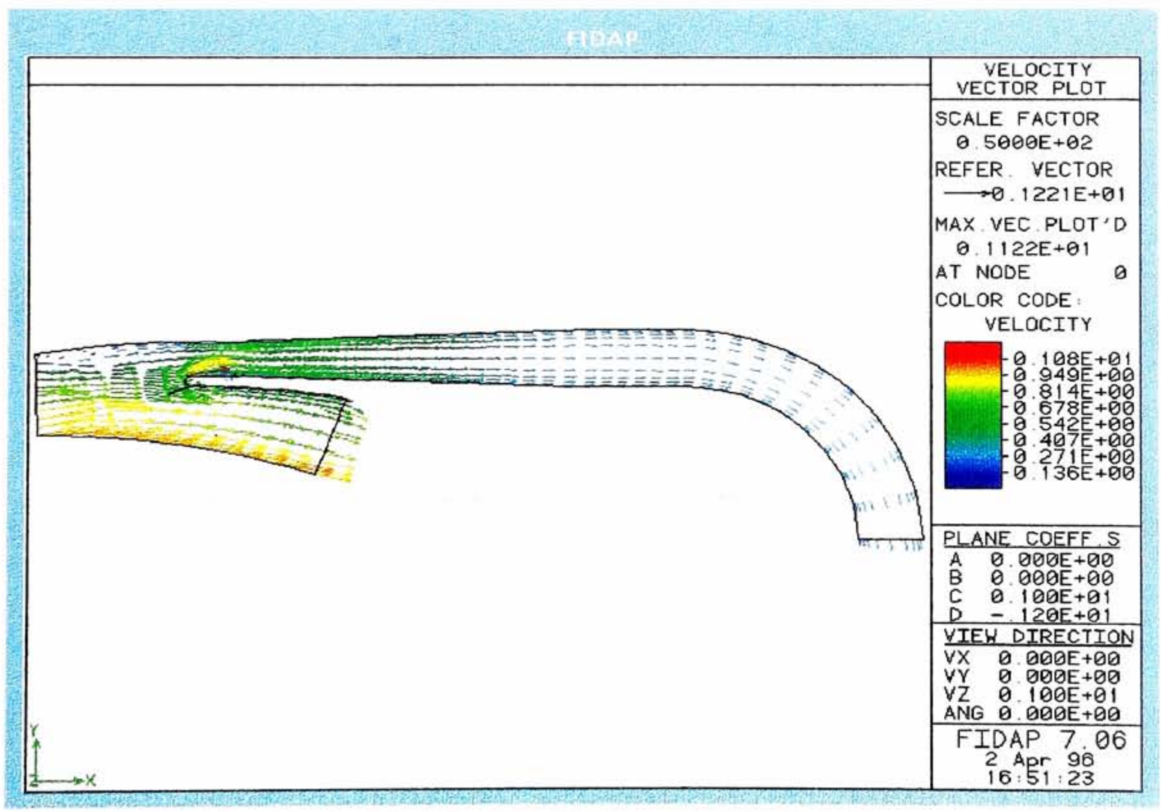


Figure 72 - 2-D View of Velocity on Shroud Side (60% - 3%)

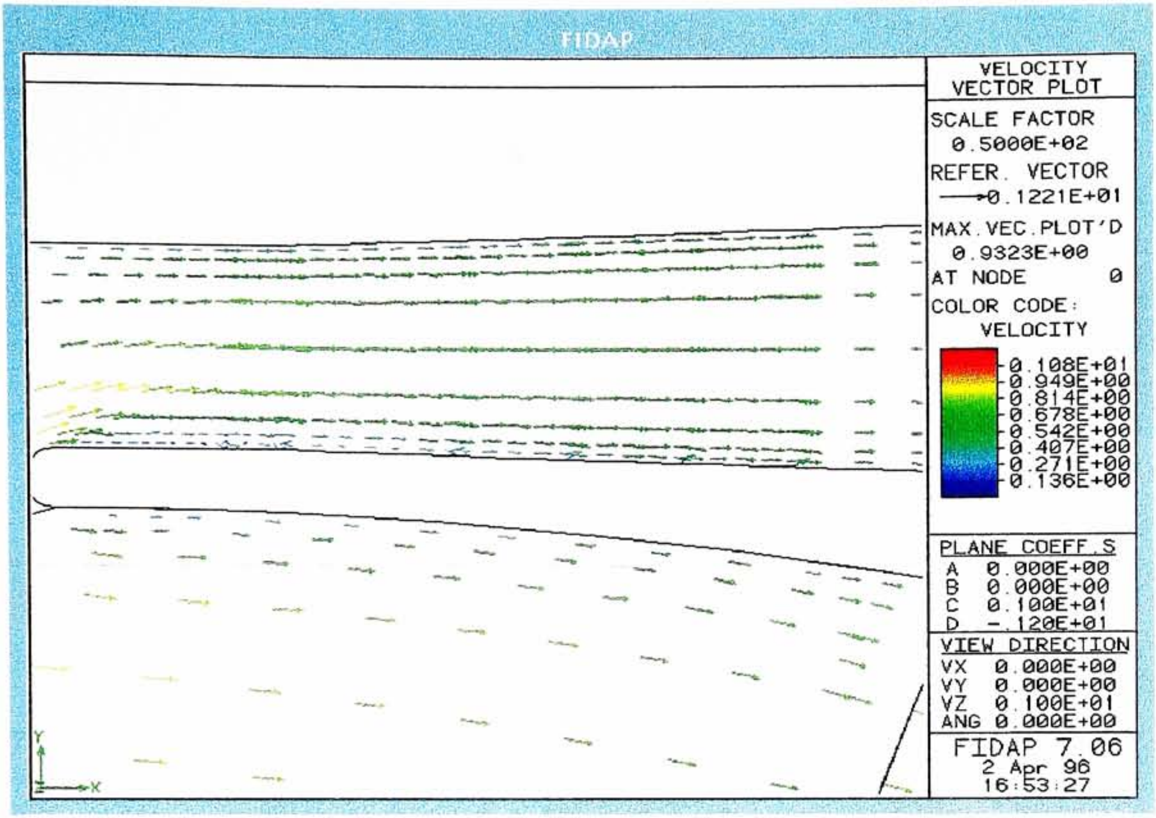


Figure 73 - Velocity at Diffuser's Throat on Shroud Side (60% - 3%)

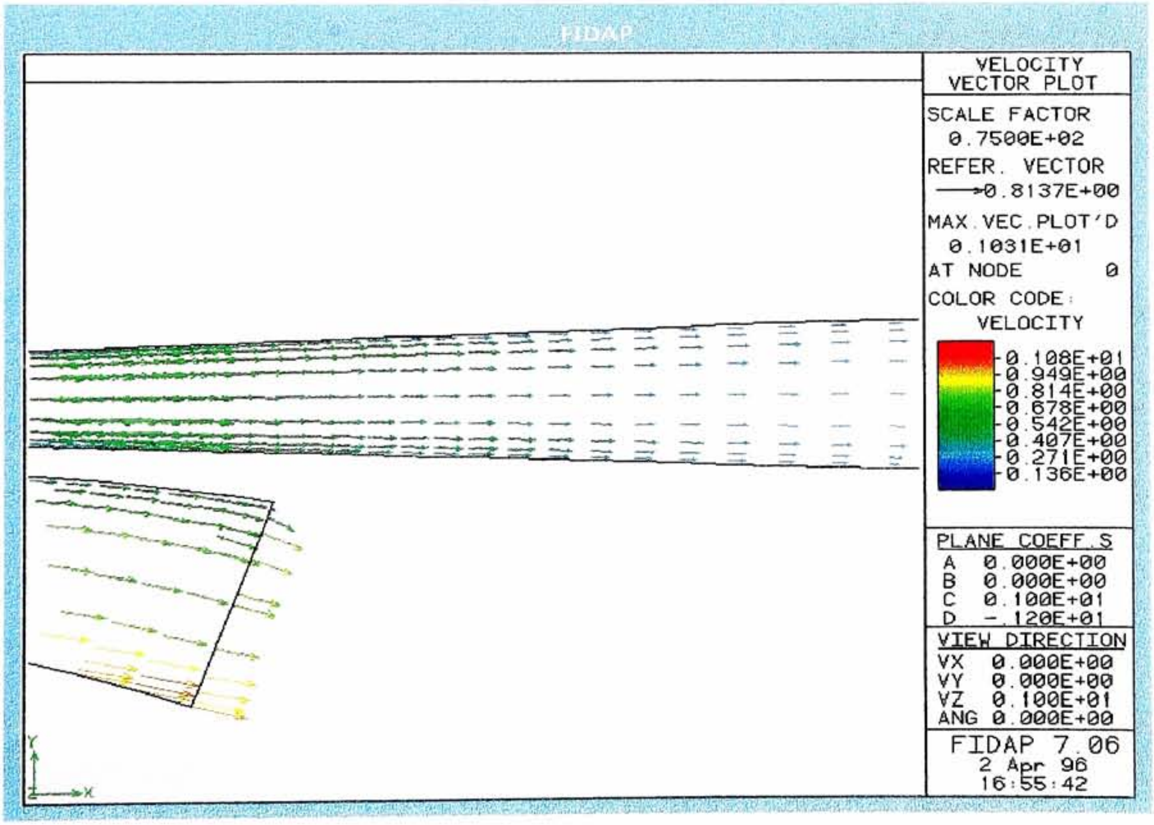


Figure 74 - Velocity at Outlet on Shroud Side (60% - 3%)

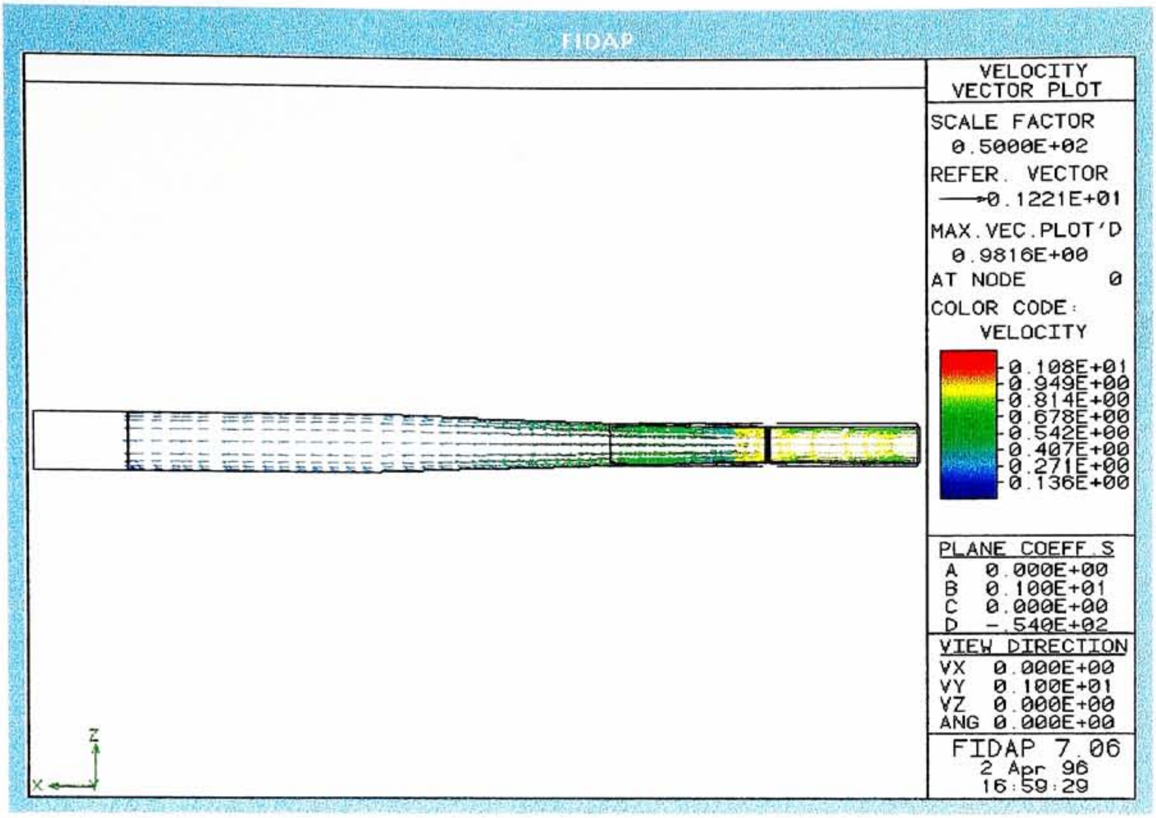


Figure 75 - 2-D View of Velocity on Bottom (60%-3%)

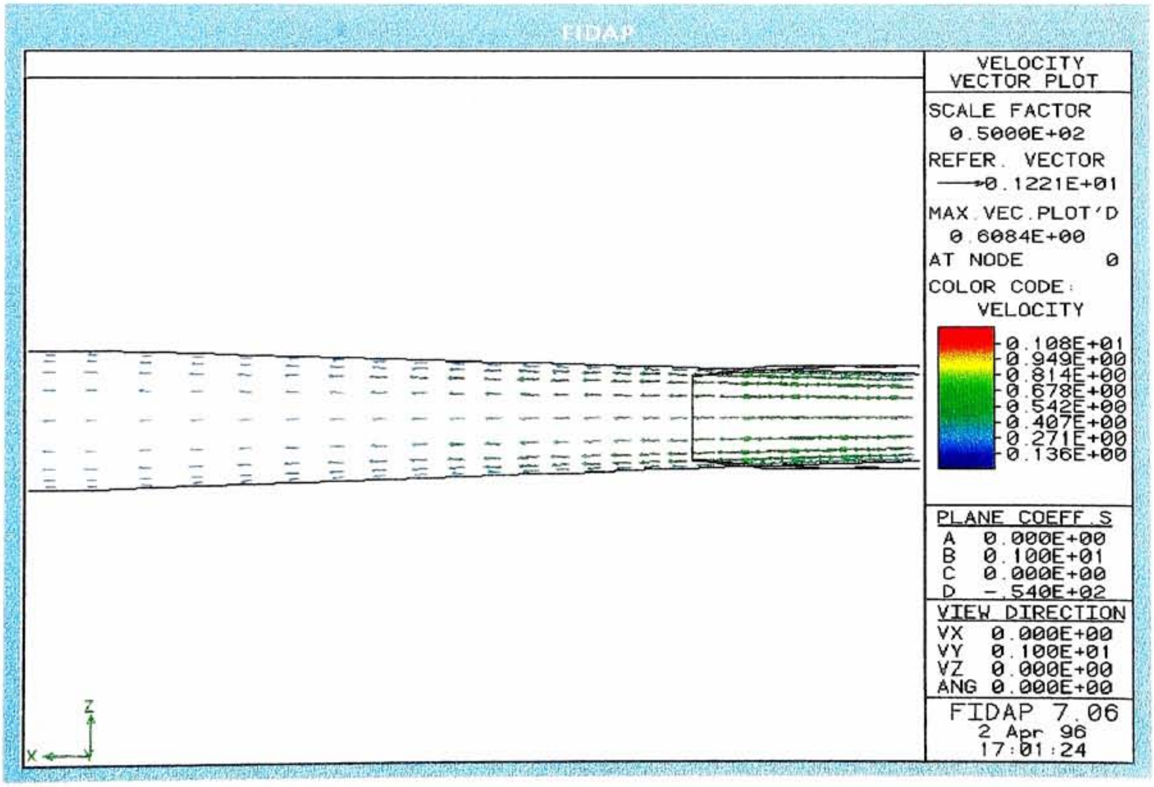


Figure 76 - Close Up of Velocity at Outlet on Bottom (60% - 3%)

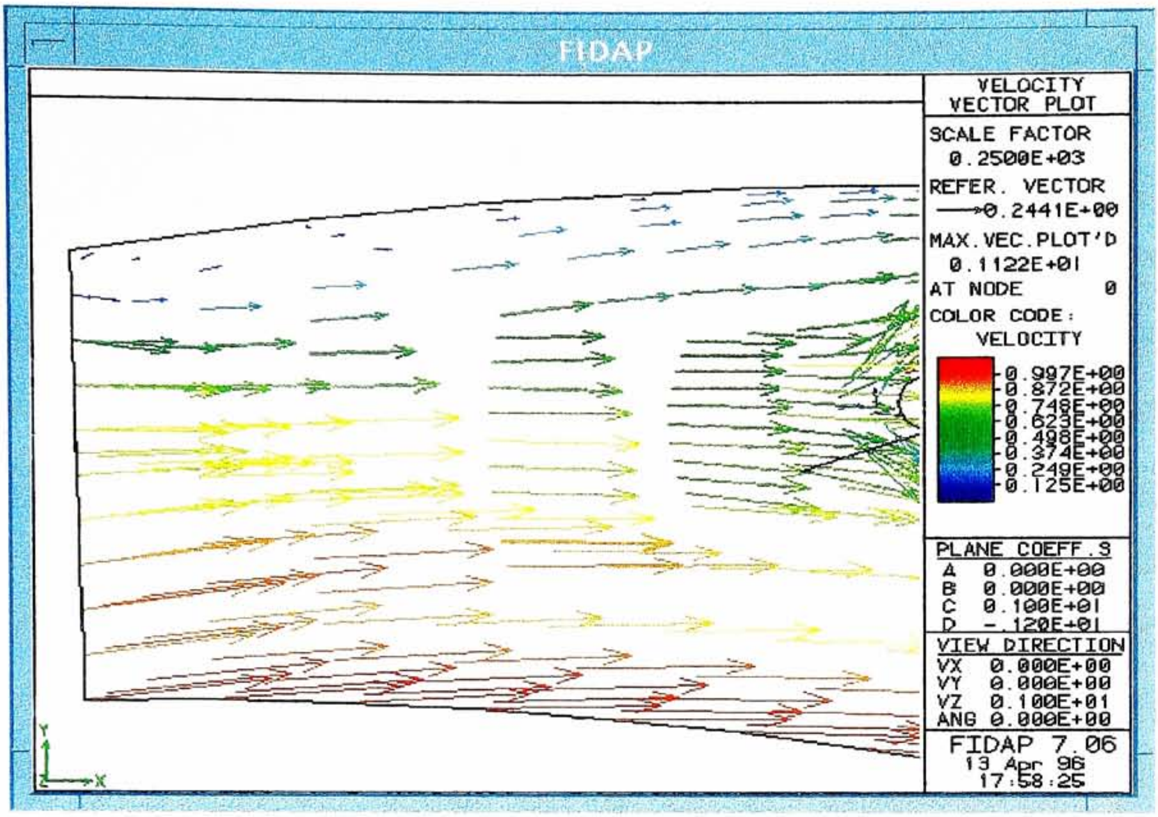


Figure 77 - Close Up on Shroud Side at the Inlet (60%-3%)

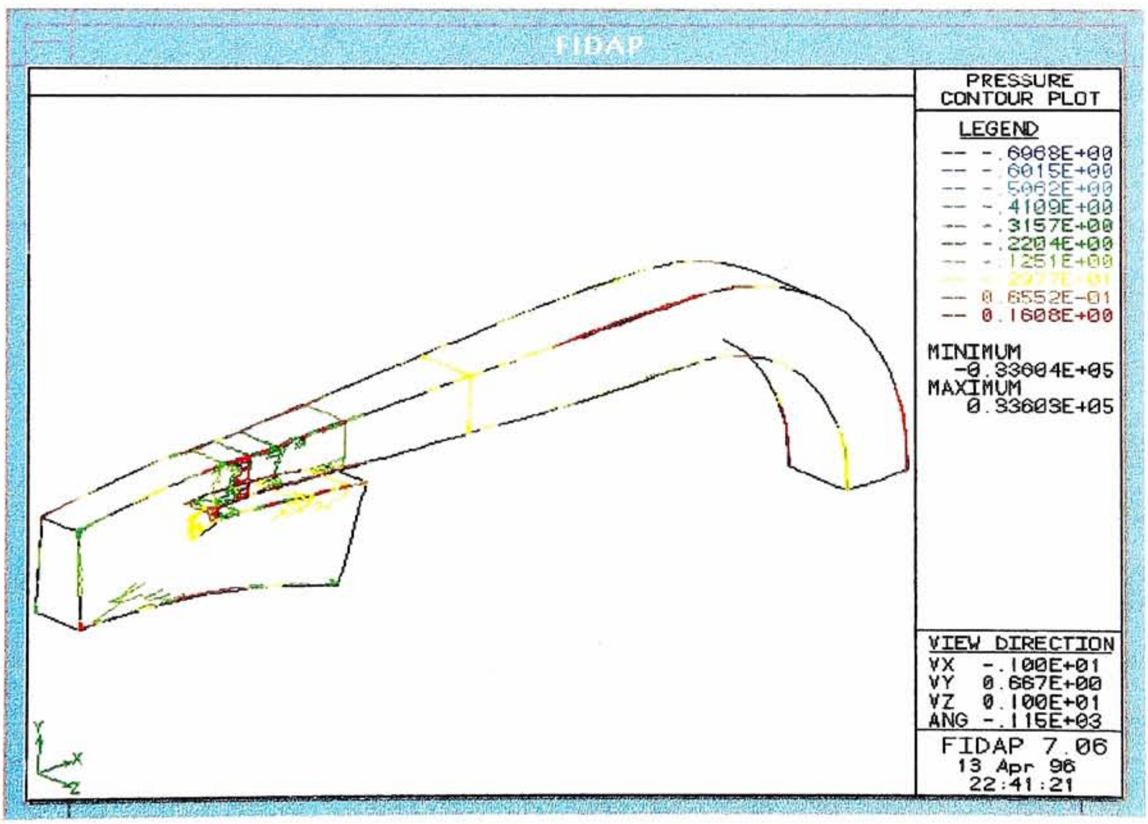


Figure 78 - Pressure Contour Plot (60% - 3%)

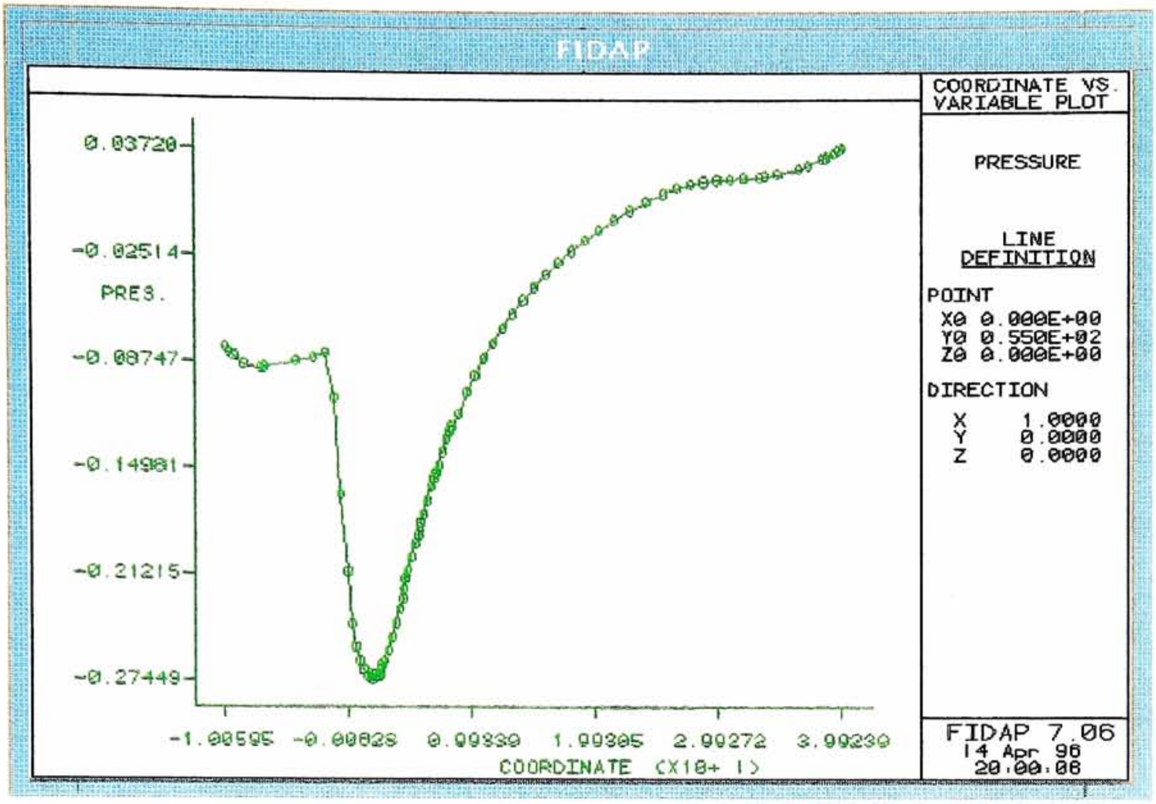


Figure 79 - Pressure Along the Centerline (60% - 3%)

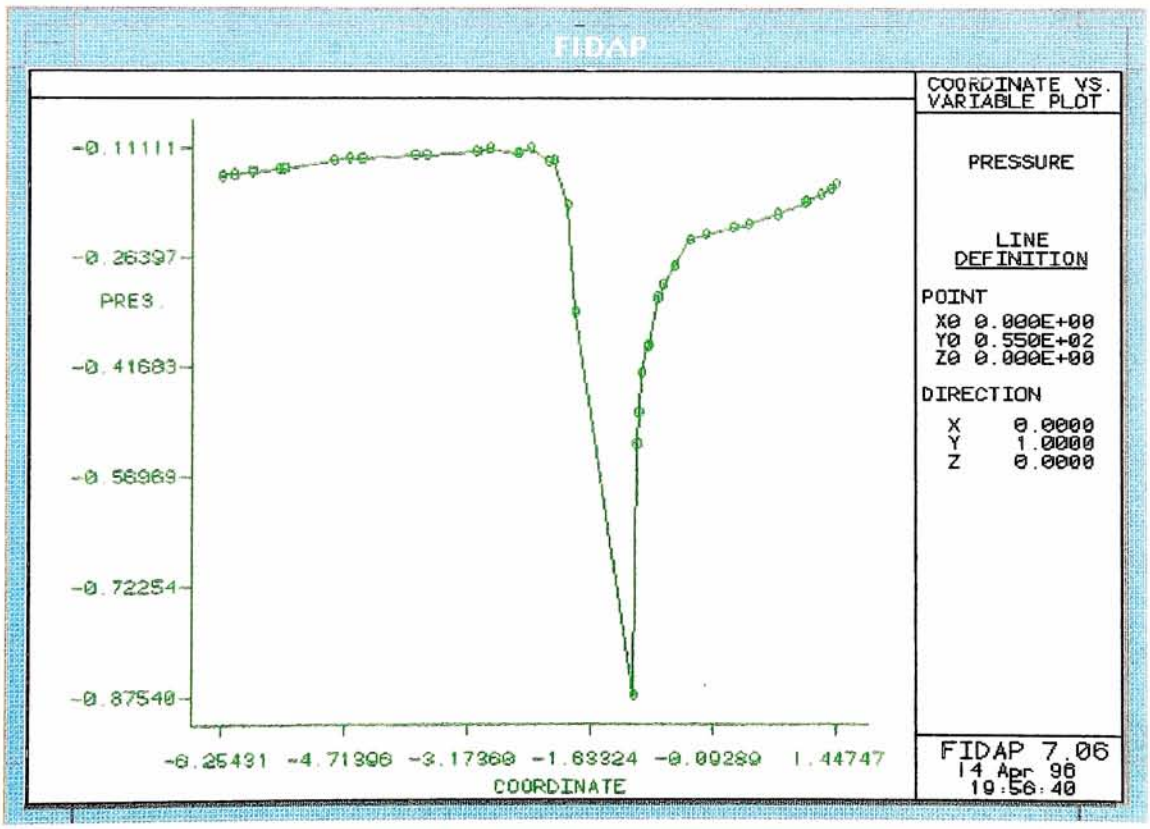


Figure 80 - Inlet Pressure (60% - 3%)

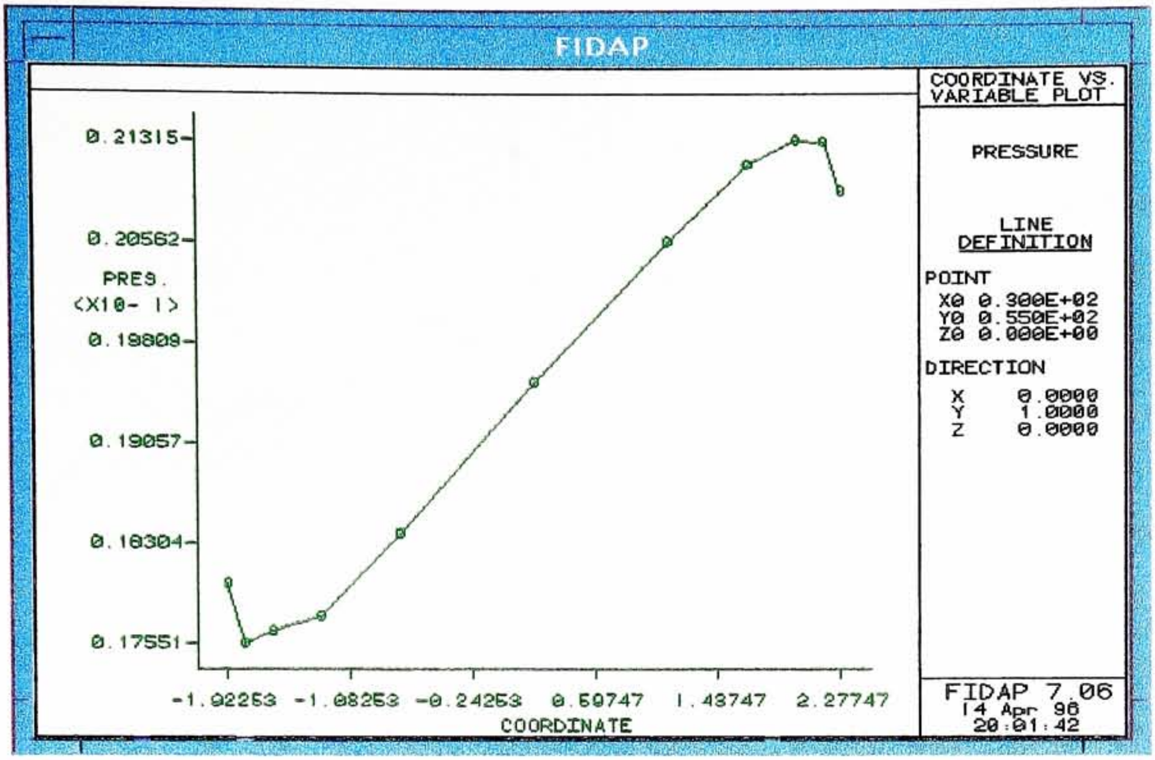


Figure 81 - Outlet Pressure (60% - 3%)

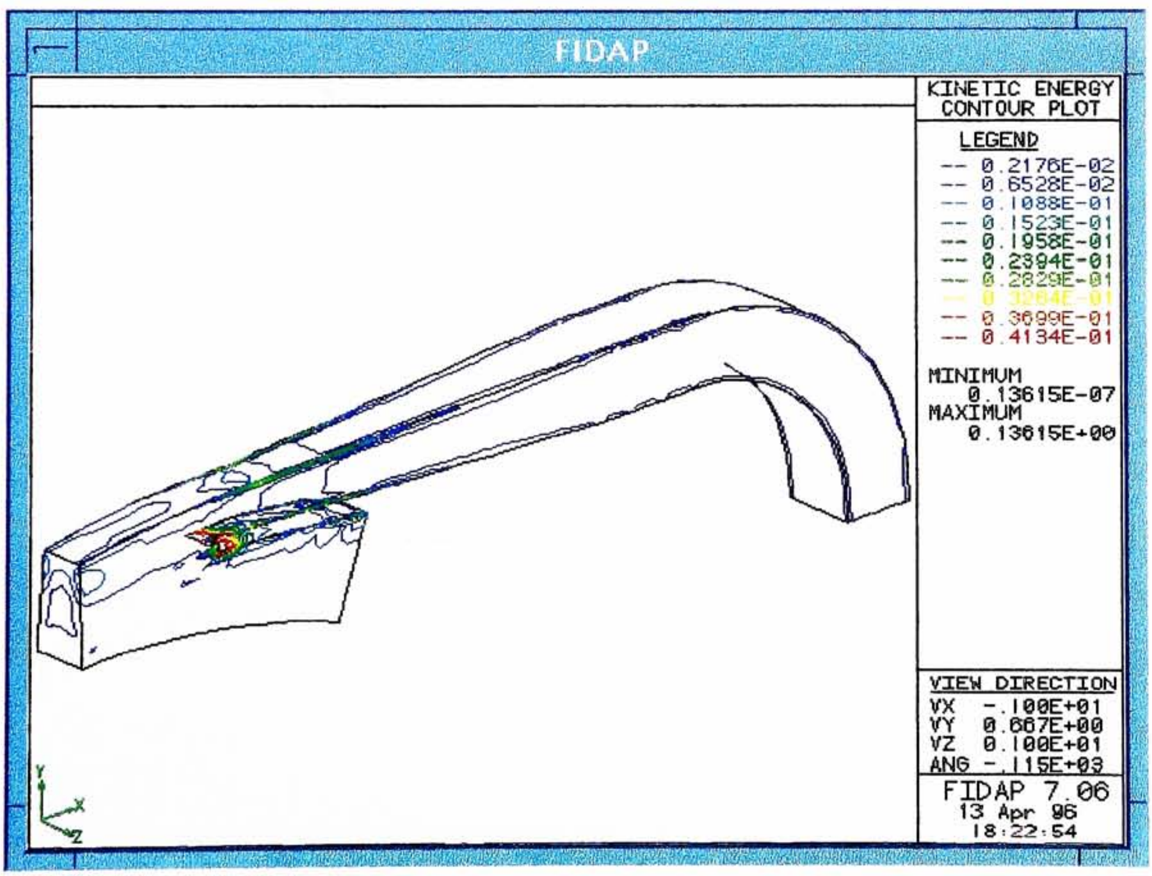


Figure 82 - Kinetic Energy Contour (60% - 3%)

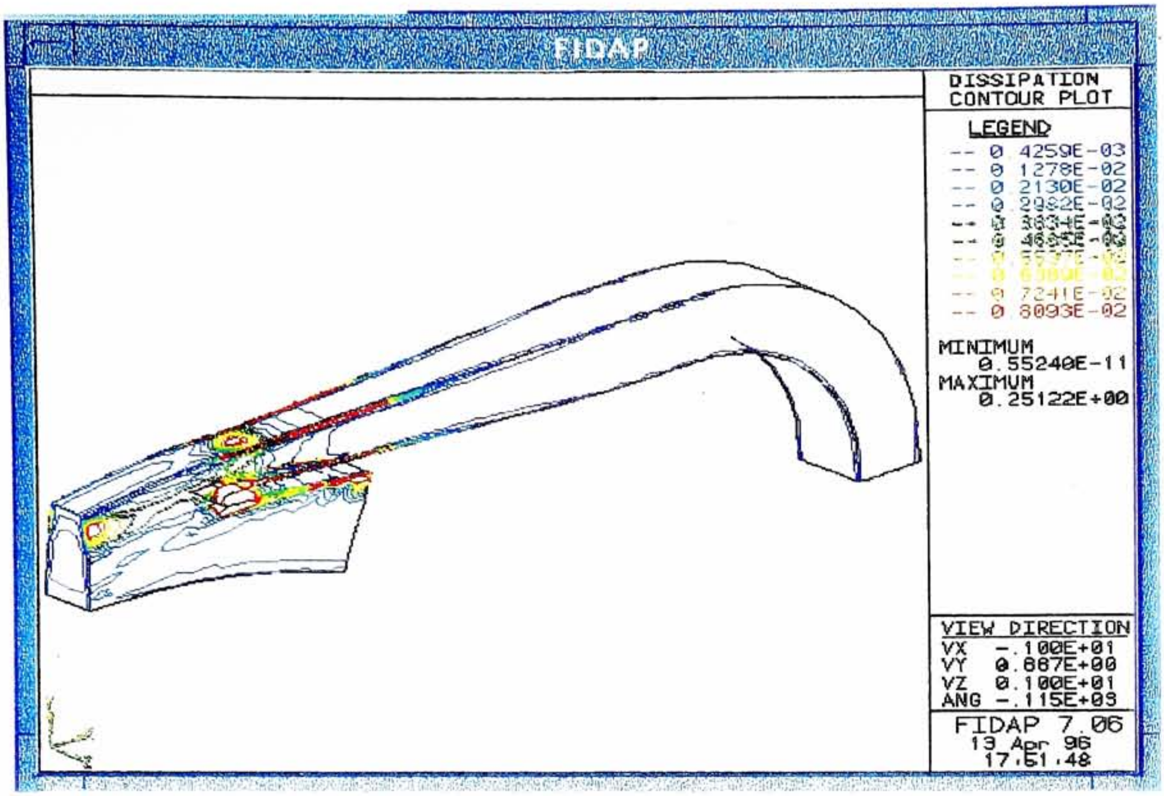


Figure 83 - Dissipation Contour Plot (60% - 3%)

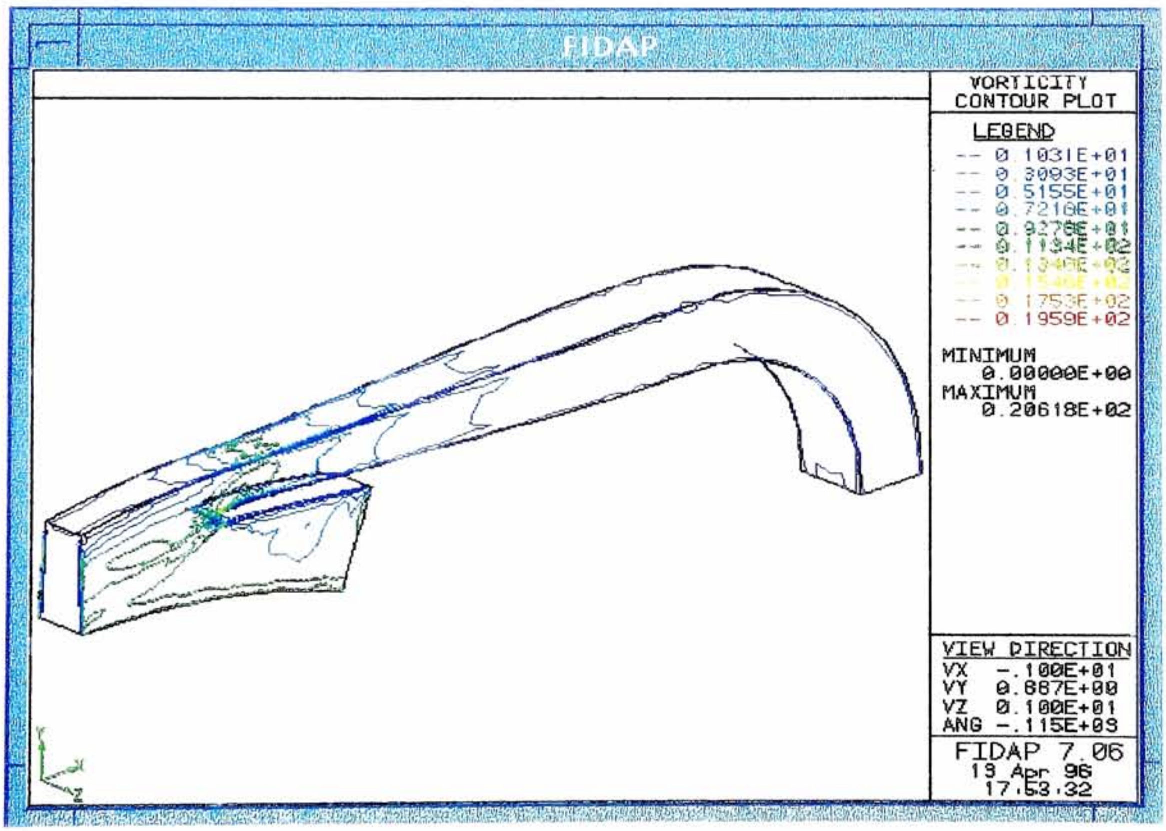


Figure 84 - Vorticity Contour Plot (60% - 3%)

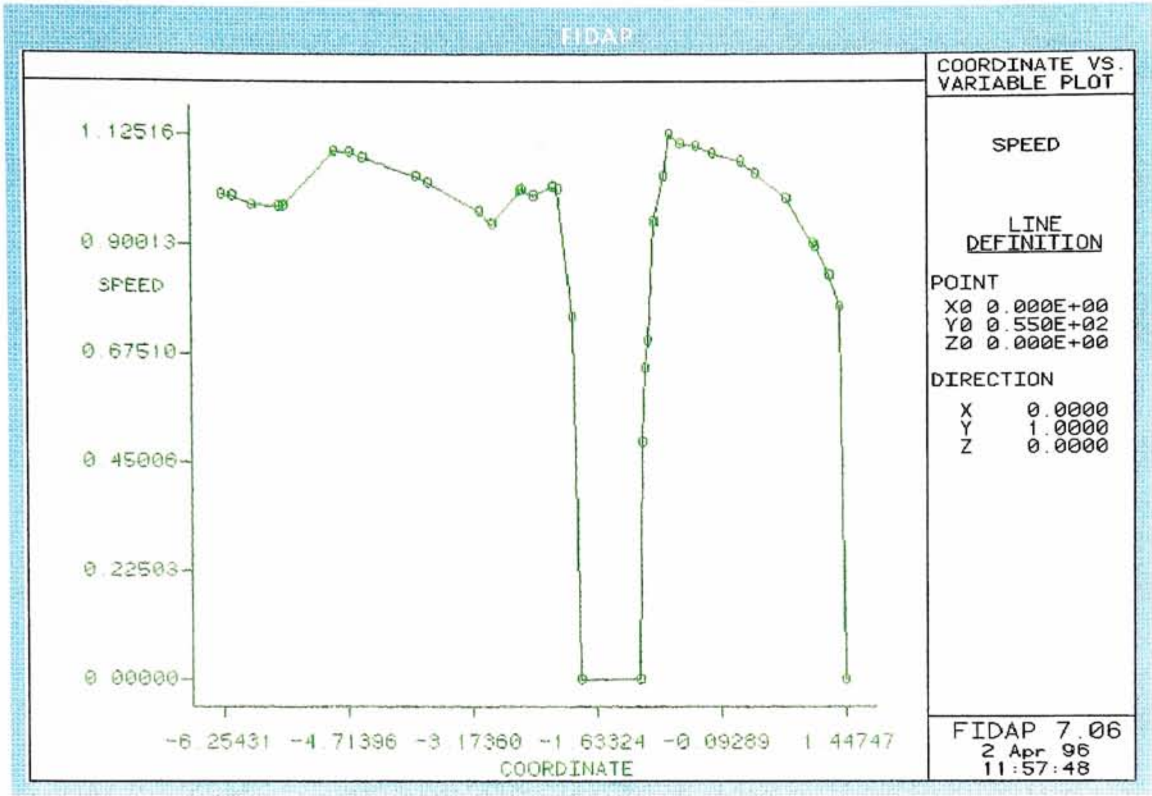


Figure 85 - Inlet Velocity Profile (60% - 3%)

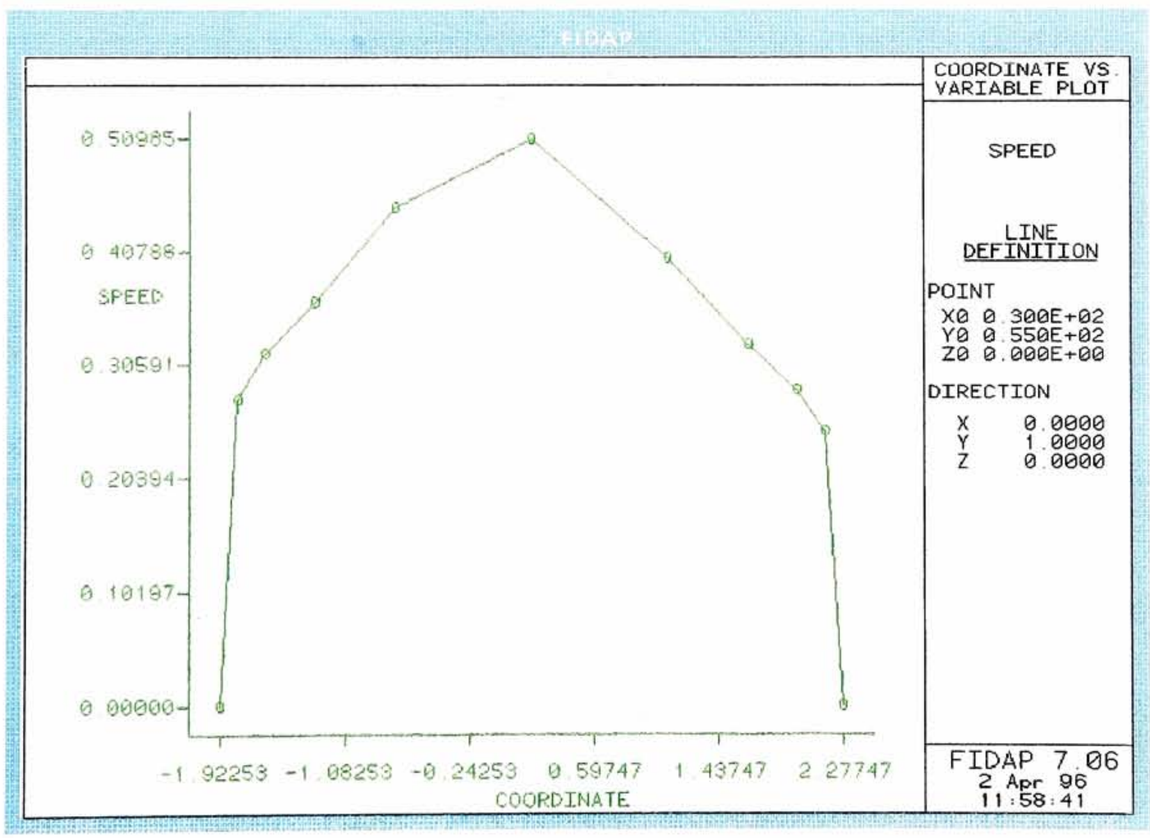


Figure 86 - Outlet Velocity Profile (60% - 3%)

7.4.2. 60% - 7% Flow Case.

The injection rate of 7% of the inlet mass flow rate through the six slits at an angle of 35 degrees, relative to the diffuser centerline, resulted in the application of a horizontal component of 0.01819 and a vertical component of 0.012738 as boundary conditions at the fluid injection slits (Refer to Appendix A for the calculations).

The velocity vector plot on the symmetry plane (Figure 87) shows a uniform flow without flow separation. The same phenomenon is observed in the shroud side plane (Figure 88) and on the bottom plane (Figure 89), which are the same planes used before to study the areas of maximum flow separation. The perpendicular views of the shroud side plane (Figure 90) and the top plane (Figure 93) also show no signs of flow separation. The effect of the injected fluid can be seen on the close ups of the shroud side. The first one (Figure 91) shows how the fluid is being injected into the diffuser and accelerates the particles that are starting to slow down near the wall. It can be seen how the amount of fluid injection doesn't affect the boundary layer. The second close up (Figure 92) shows the behavior of the fluid in the diffuser outlet and once again it can be seen that there is no flow separation. The same behavior can be observed in the close up of the perpendicular view of the velocity vector on the bottom plane (Figure 94).

As it was shown in the other cases, flow separation also was found in the shroud side of the diffuser's vaneless region (Figure 95). Secondary flow effects are probably the responsible for the creation of this area of flow separation. The pressure contour plot (Figure 96) and the pressure line along the centerline (Figure 97) indicate a relatively uniform conversion of dynamic head to static pressure as the diffuser is traversed in the direction of flow. Using the pressure line plots from the bottom of the diffuser to the top, at the diffuser inlet (Figure 98) and outlet (Figure 99), the pressure recovery coefficient was calculated to be 0.6515. The increase in the percentage of fluid being injected in the diffuser doesn't seem to improve the performance of the diffuser. In order to determine this it is important to observe the characteristics of the flow in the diffuser as well as the value of the pressure recovery coefficient. For the 60%-3% flow case, the value of Cp came out to be 0.6776, while for the 60% - 7% flow case the value of Cp was calculated to be 0.6515. These results indicate that the optimum value of fluid injection should be found either between 3% and 7% or between 0% and 3% of the mass flow rate.

The kinetic energy (Figure 100), dissipation (Figure 101), and vorticity (Figure 102) contour plots are included for flow verification. The majority of the kinetic energy is generated at the diffuser's entrance region on both the top and bottom planes near the shroud side wall, with a corresponding amount of dissipation in the same area. The vorticity, which is an indication of the level of viscosity present in the fluid at a particular location, shows also this behavior. This could be caused by the injection of fluid in this part of the diffuser. The velocity profiles that were graphed at positions near the diffuser inlet (Figure 103) and outlet (Figure 104) of the diffuser on the symmetry plane and are typical of turbulent flow in a diffuser. The inlet velocity profile shows the flow separation that occurs in the entrance to the vaneless section and the outlet velocity profile shows the significant reduction in the flow speed that is present in the diffuser's bottom plane near the shroud side.

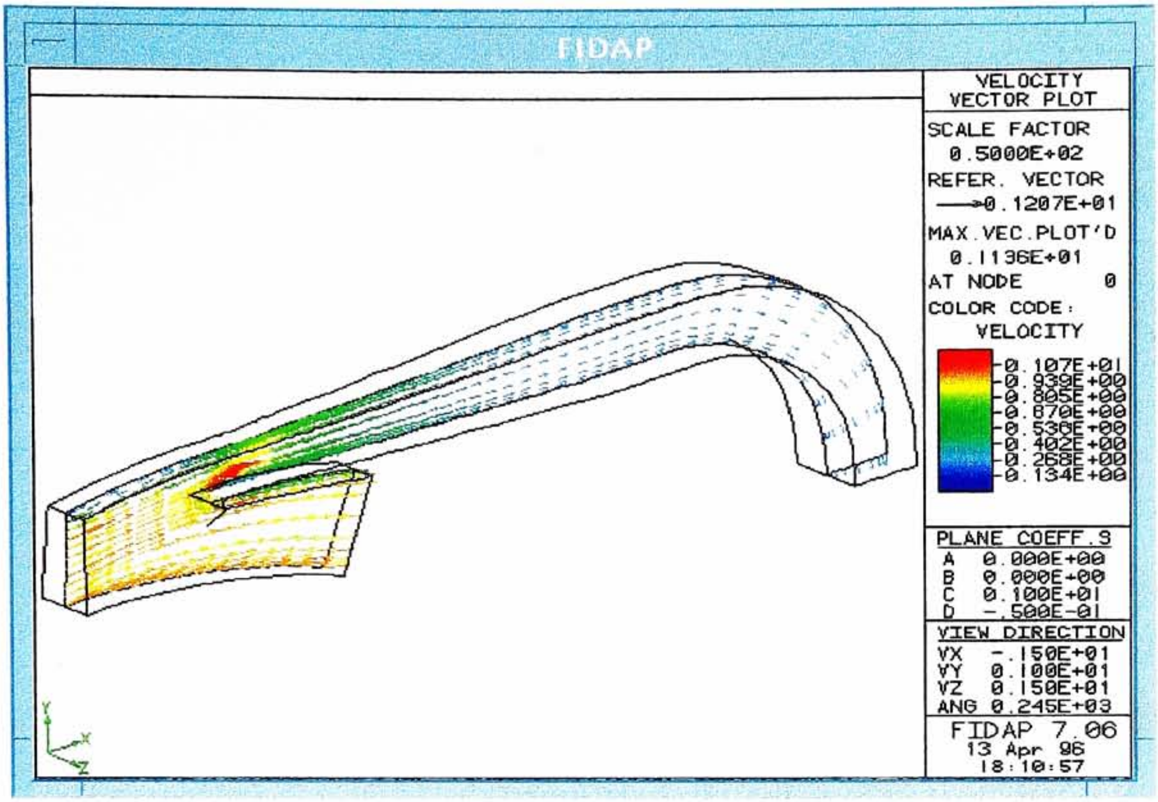


Figure 87 - Velocity on Symmetry Plane (60% - 7%)

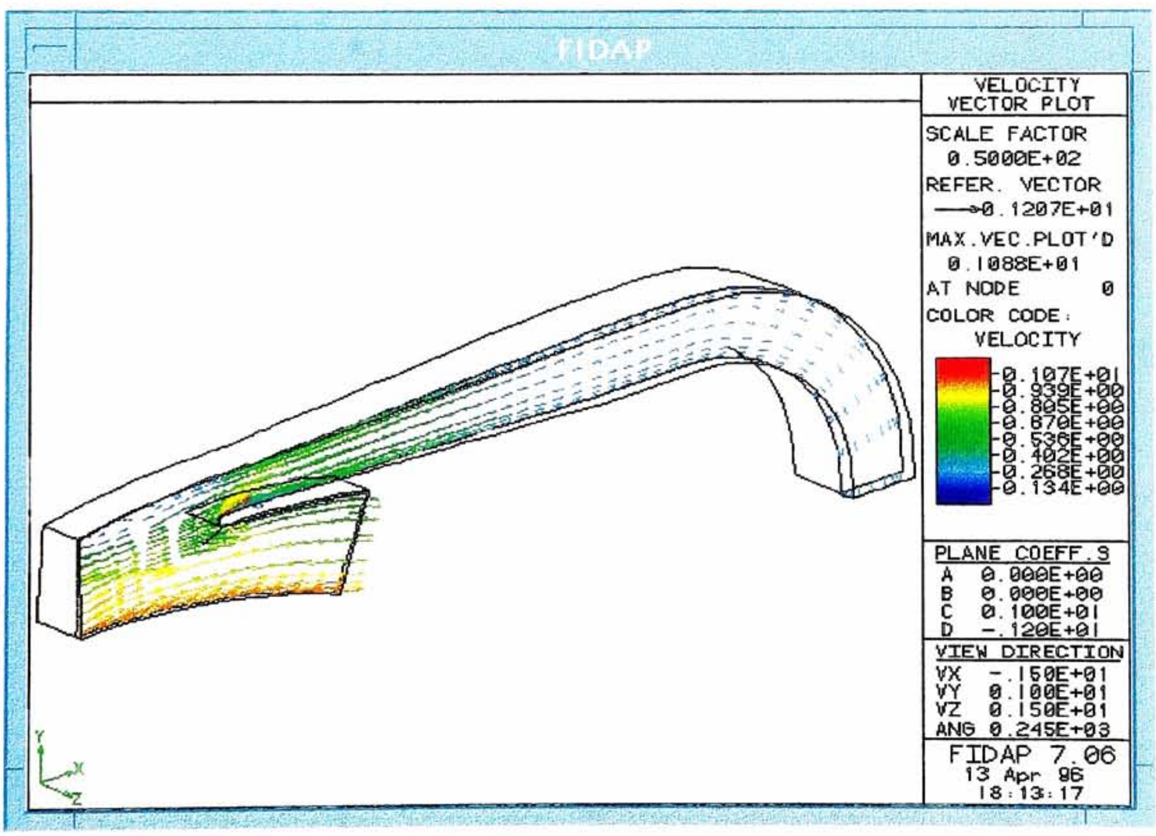


Figure 88 - Velocity on Shroud Side Plane (60% - 7%)

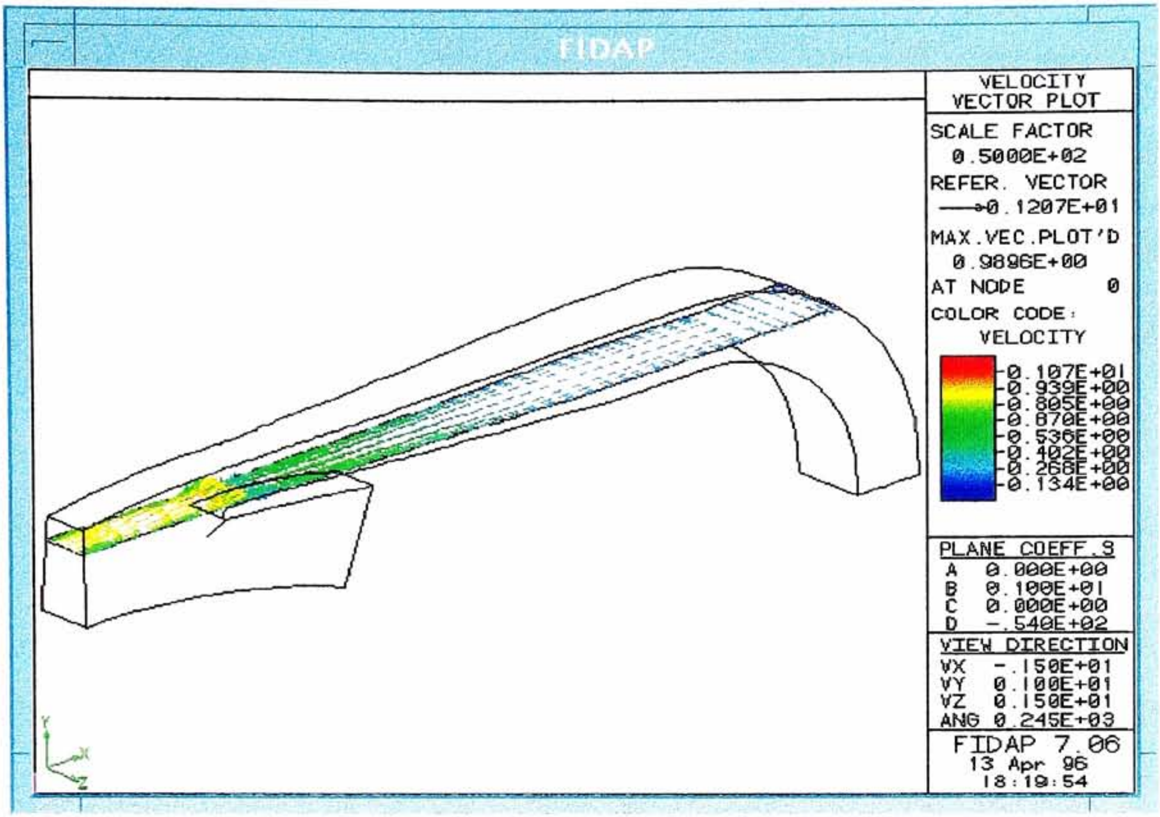


Figure 89 - Velocity on Bottom Plane (60% - 7%)

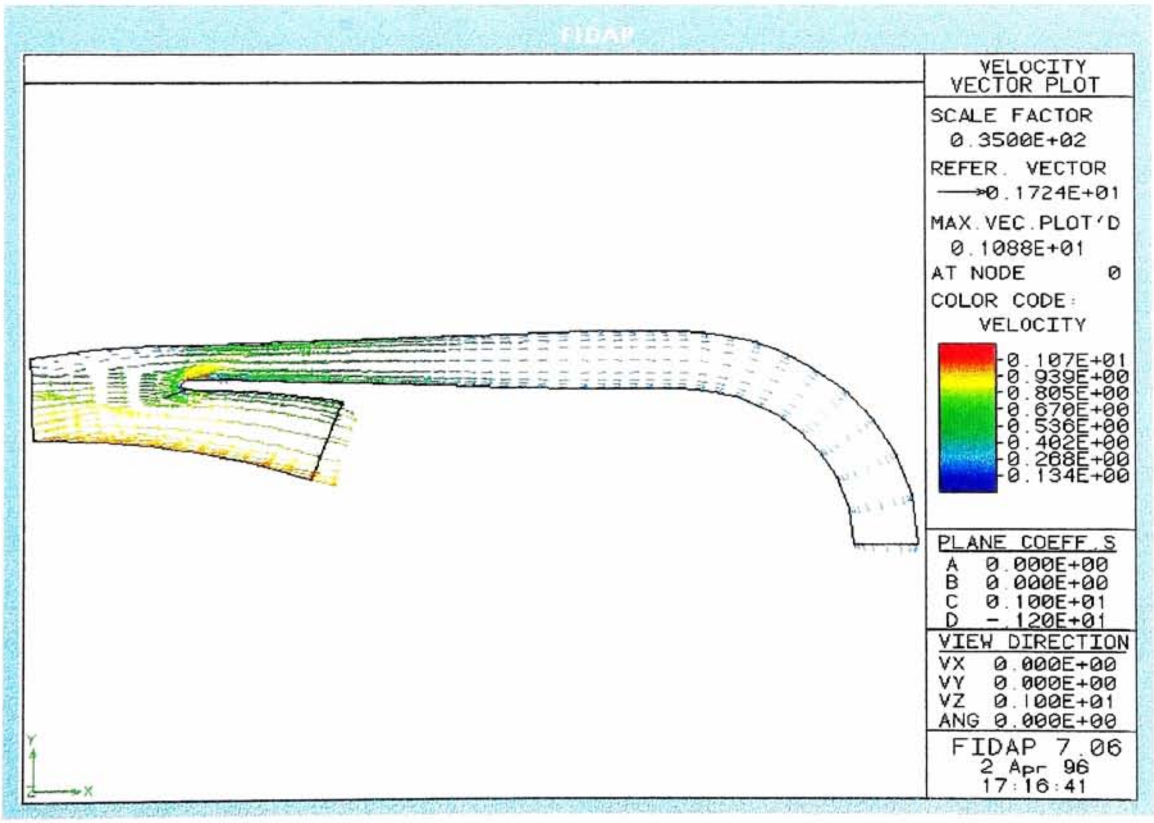


Figure 90 - 2-D View of Velocity on Shroud Side (60% - 7%)

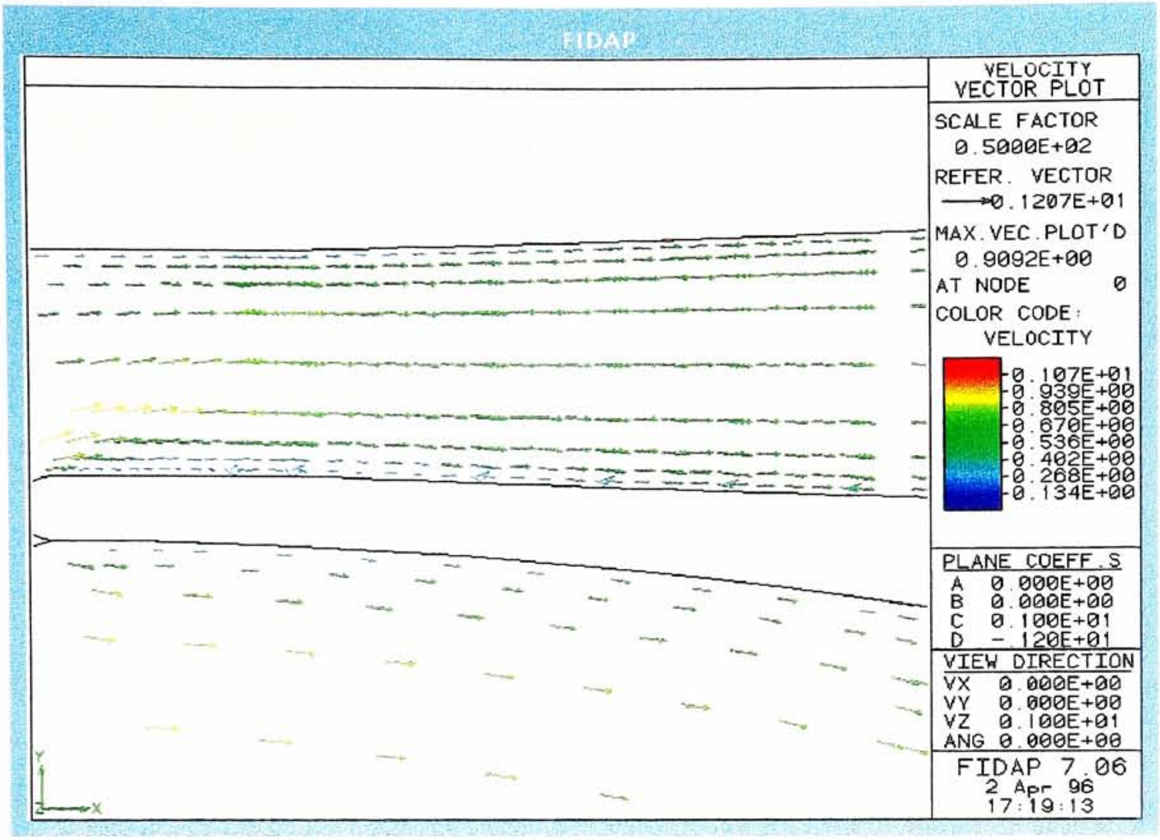


Figure 91 - Velocity at Diffuser's Throat on Shroud Side (60% - 7%)

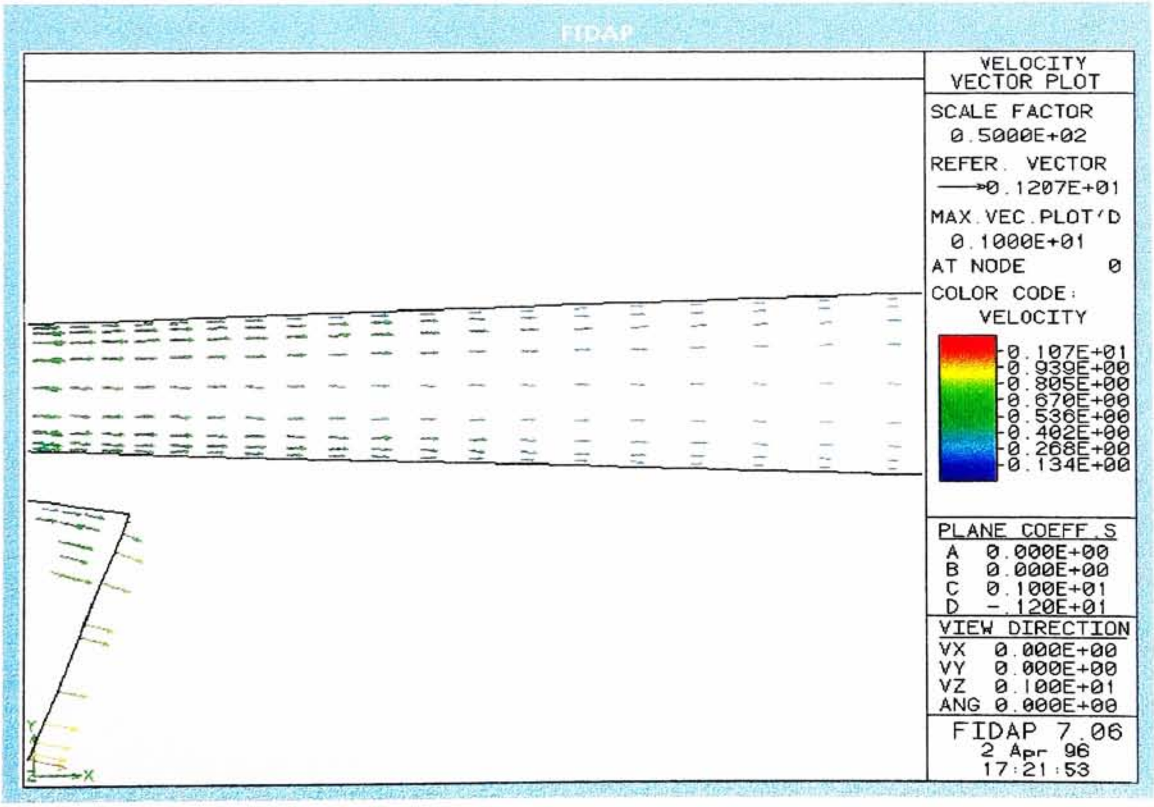


Figure 92 - Velocity at Outlet on Shroud Side (60% - 7%)

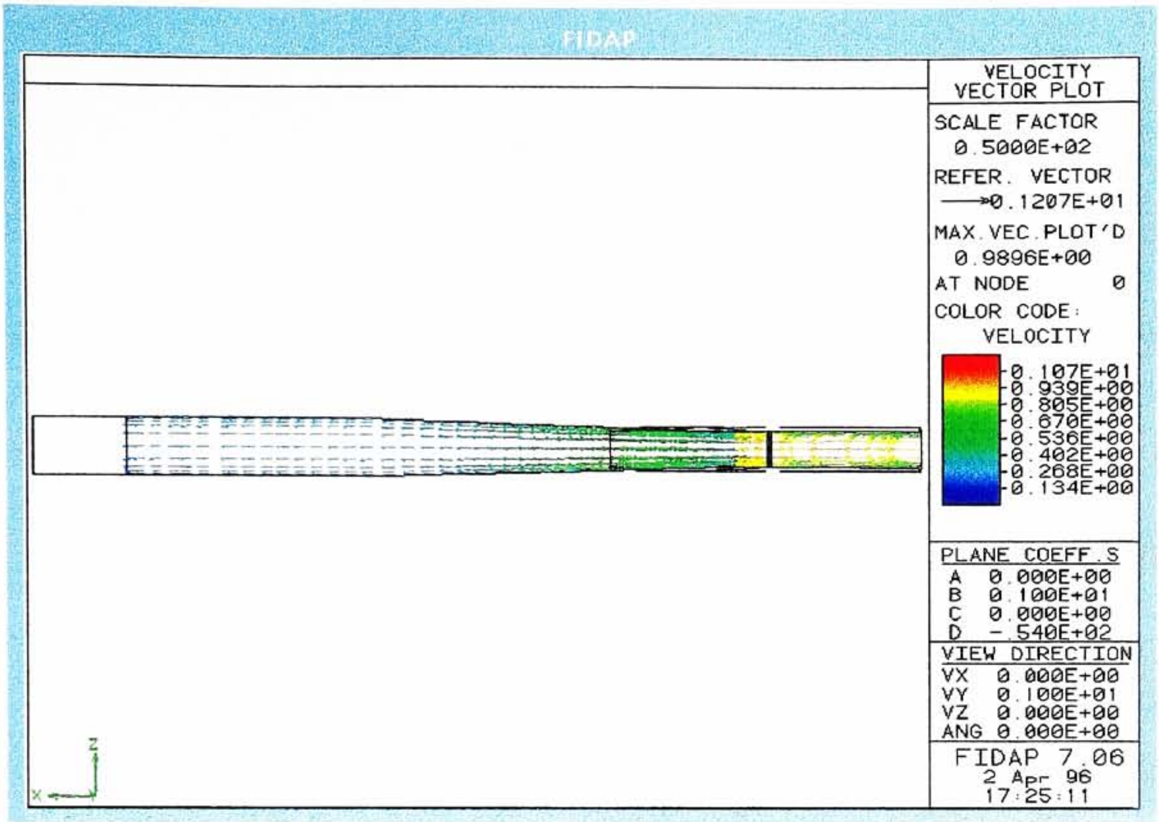


Figure 93 - 2-D View of Velocity on Bottom (60% - 7%)

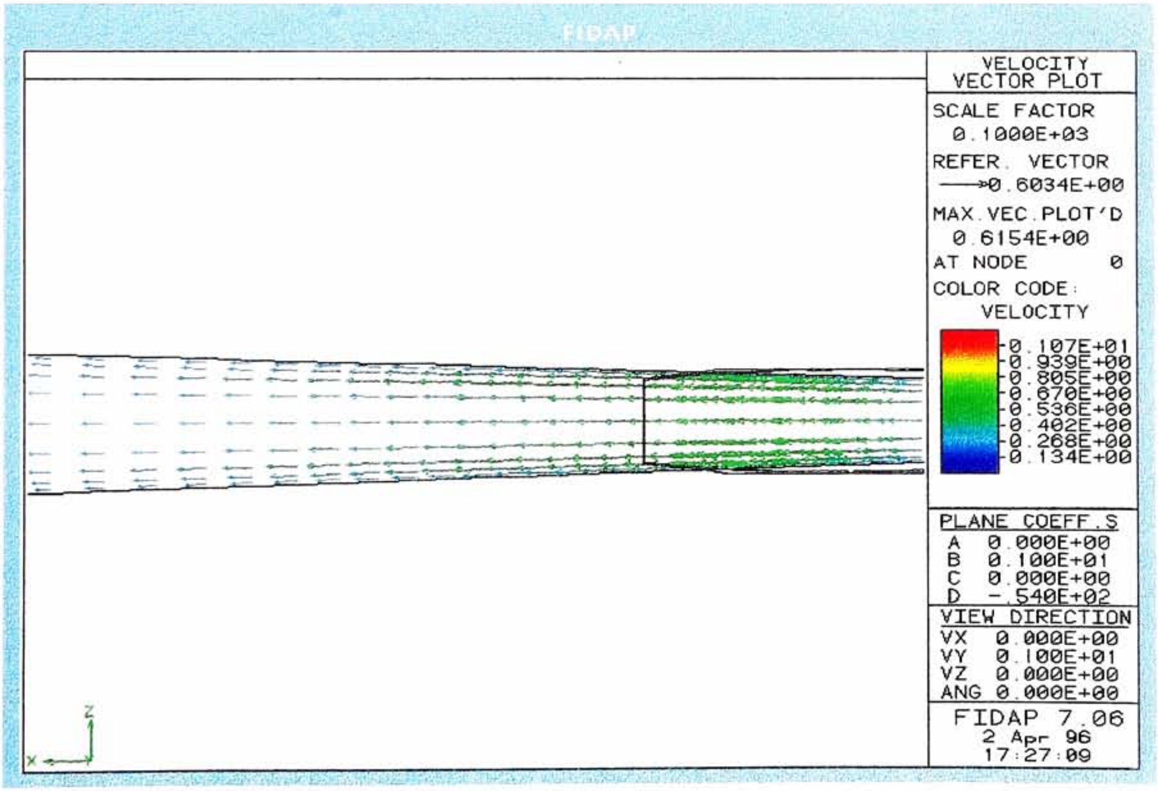


Figure 94 - Close Up of Velocity at Outlet on Shroud Side (60% - 7%)

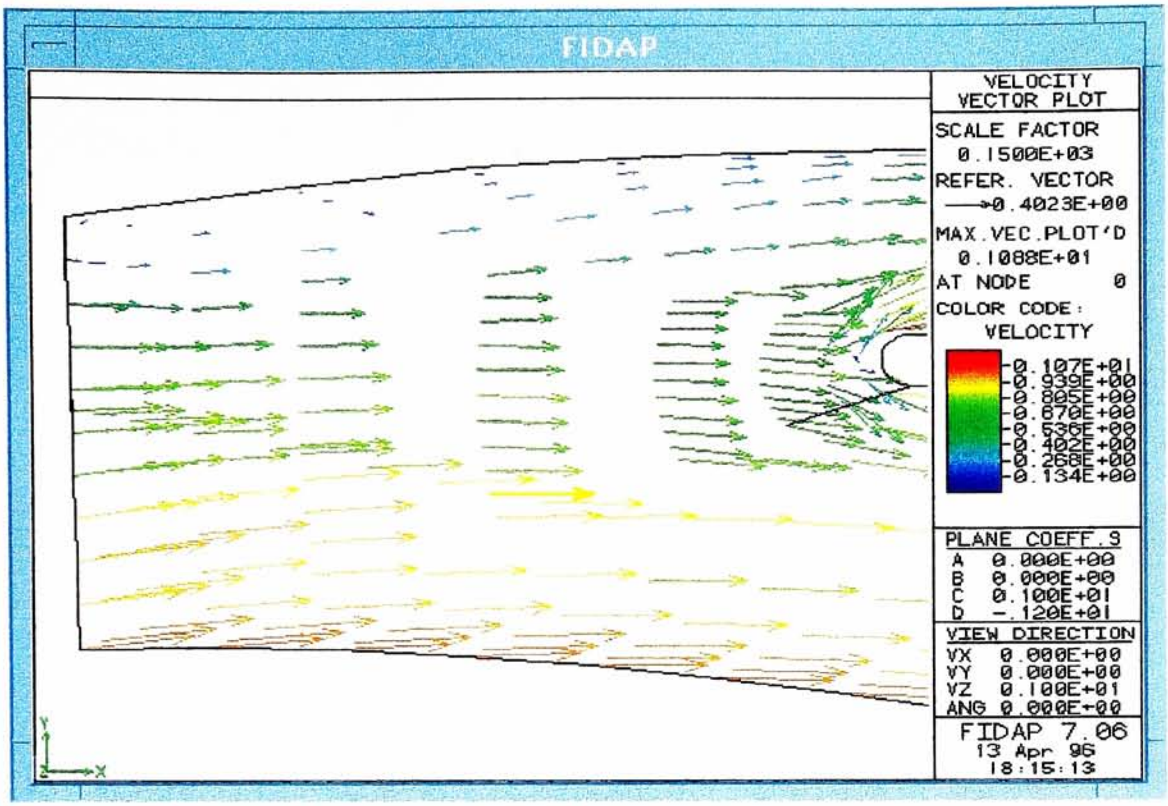


Figure 95 - Close Up on Shroud Side at the Inlet (60%-7%)

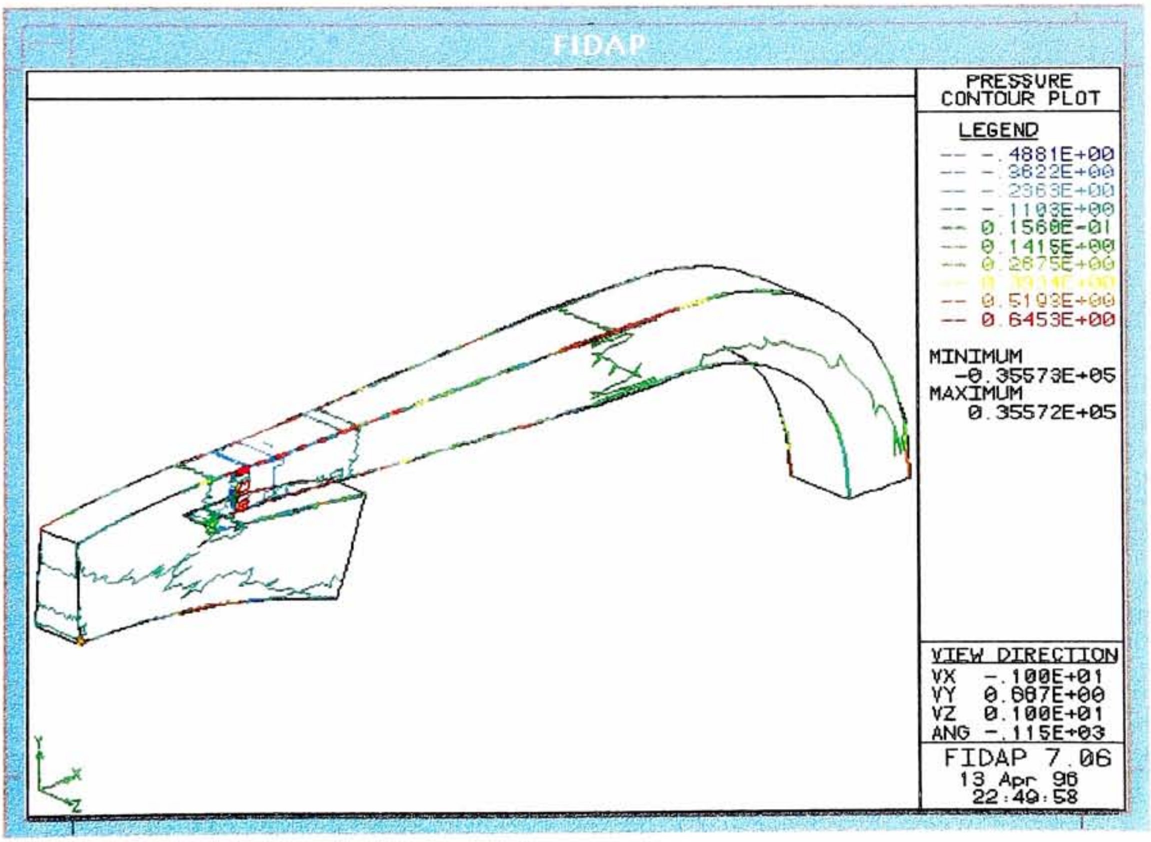


Figure 96 - Pressure Contour Plot (60% - 7%)

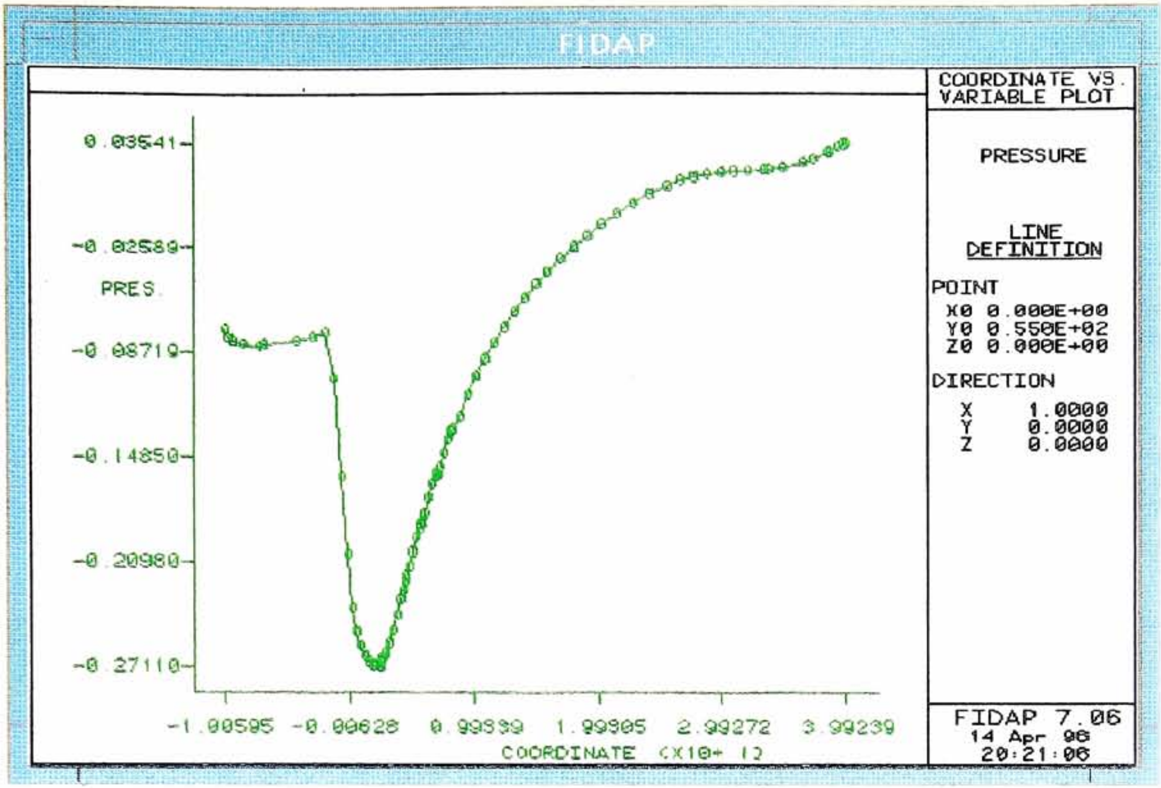


Figure 97 - Pressure Along the Centerline (60% - 7%)

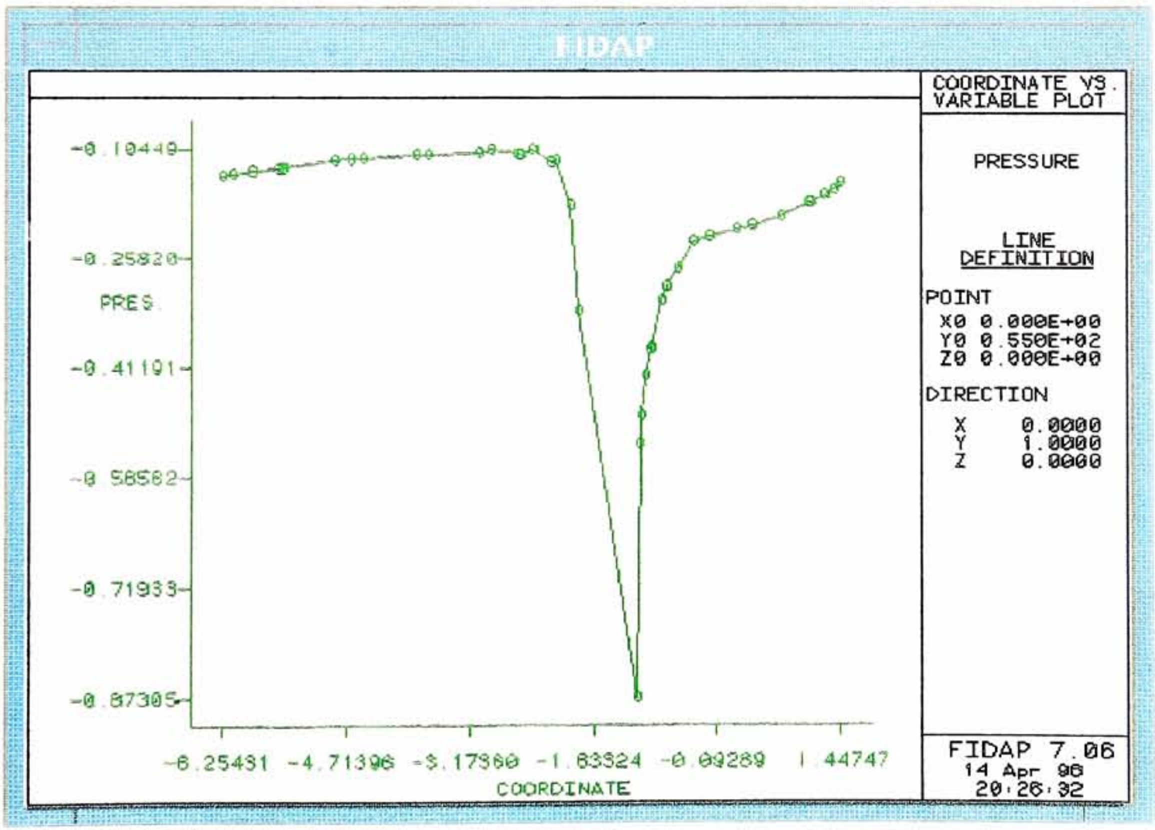


Figure 98 - Inlet Pressure (60% - 7%)

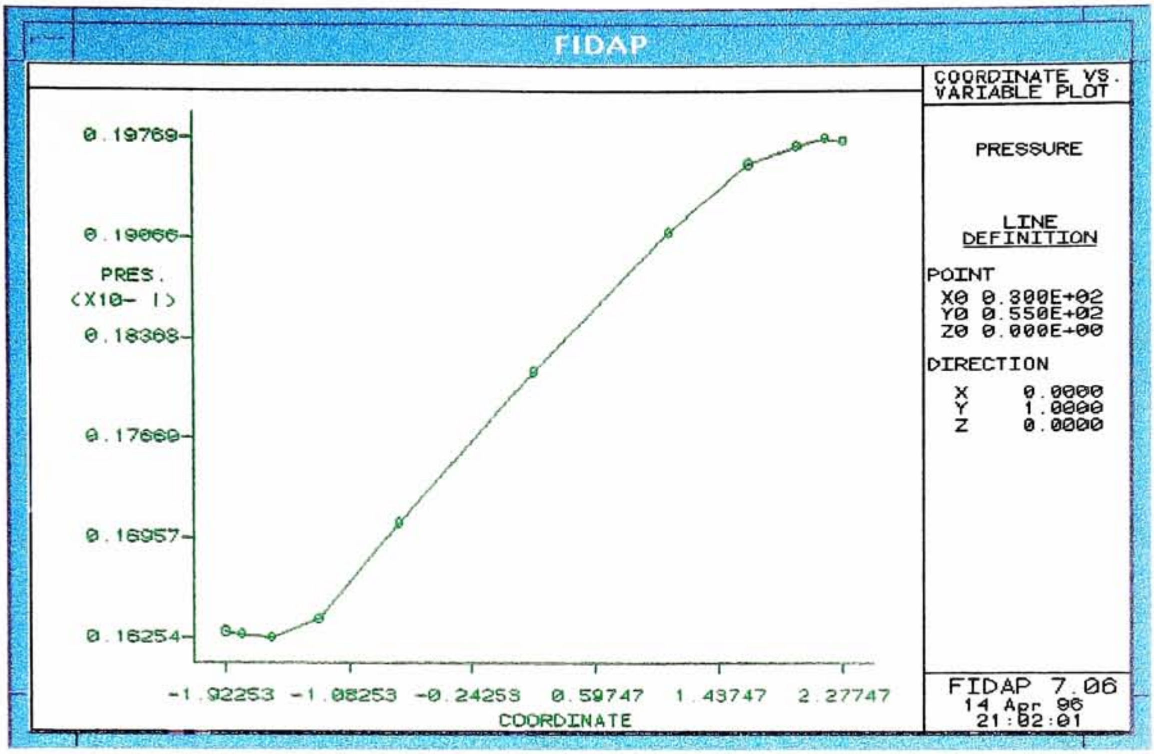


Figure 99 - Outlet Pressure (60% - 7%)

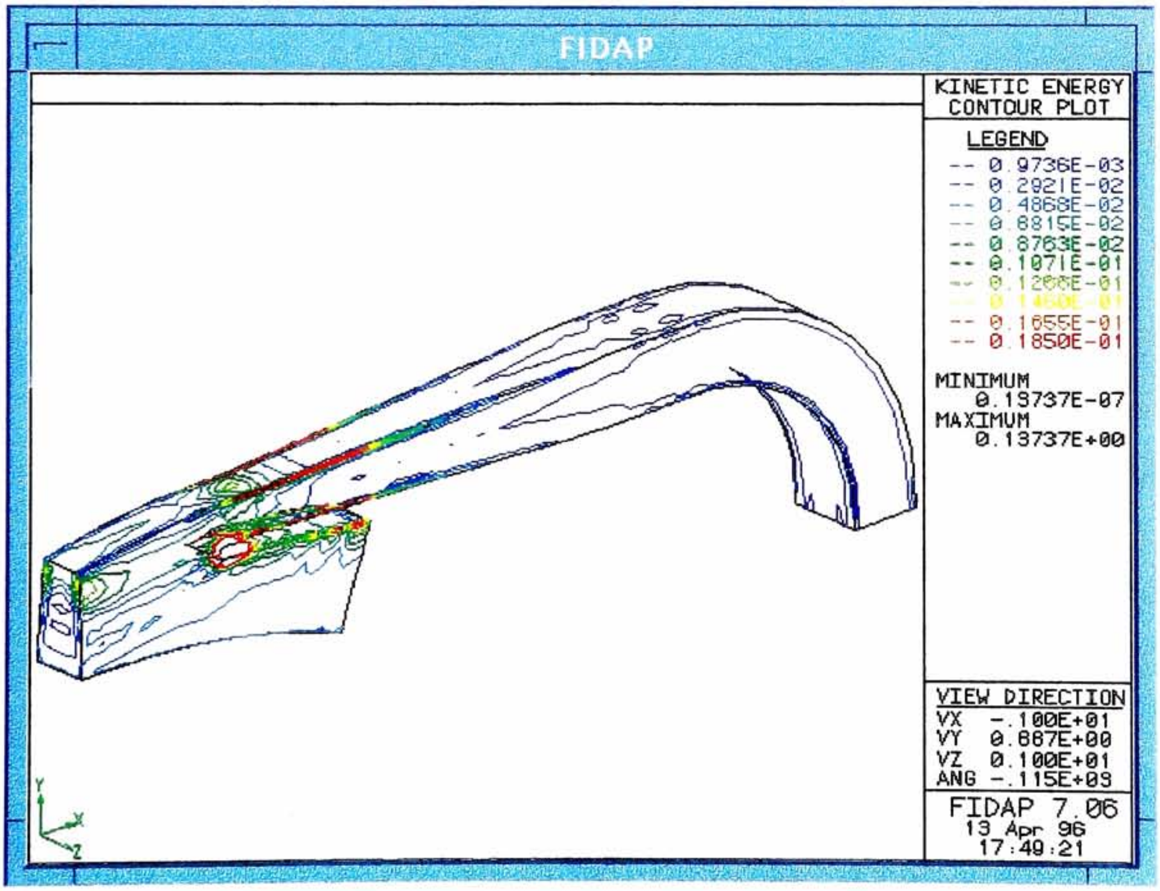


Figure 100 - Kinetic Energy Contour (60% - 7%)

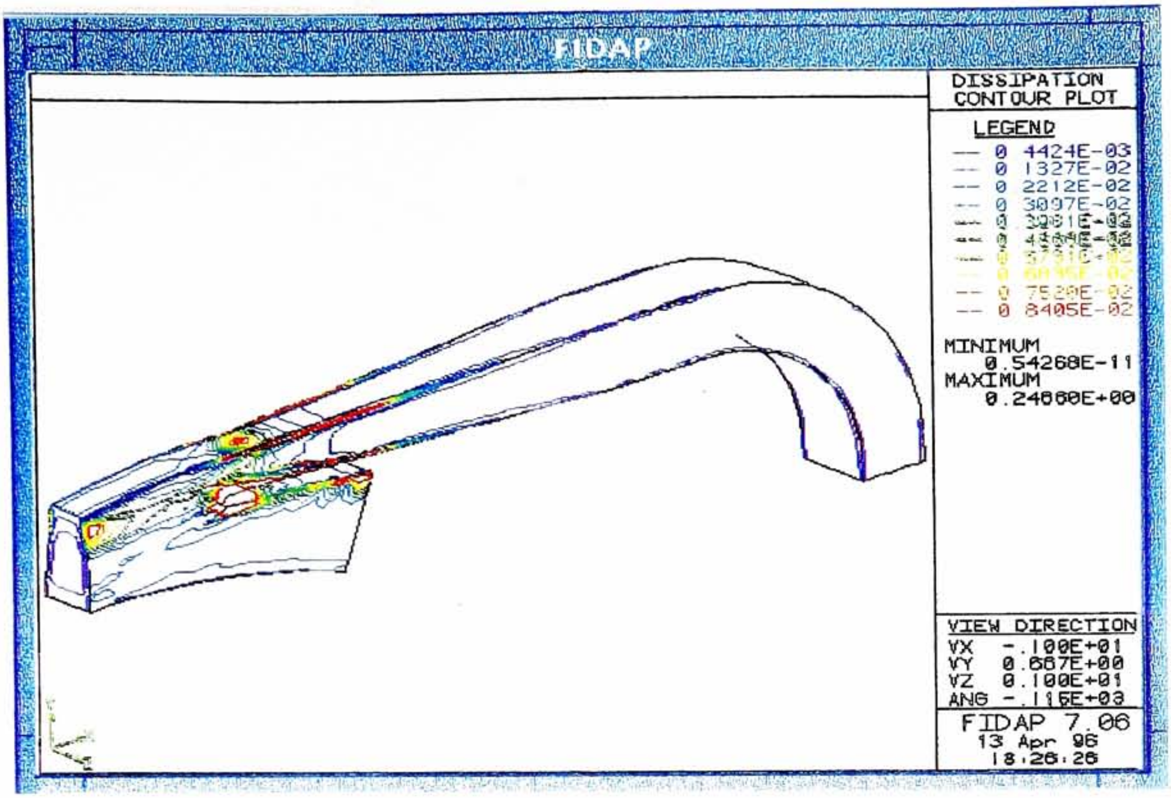


Figure 101 - Dissipation Contour Plot (60% - 7%)

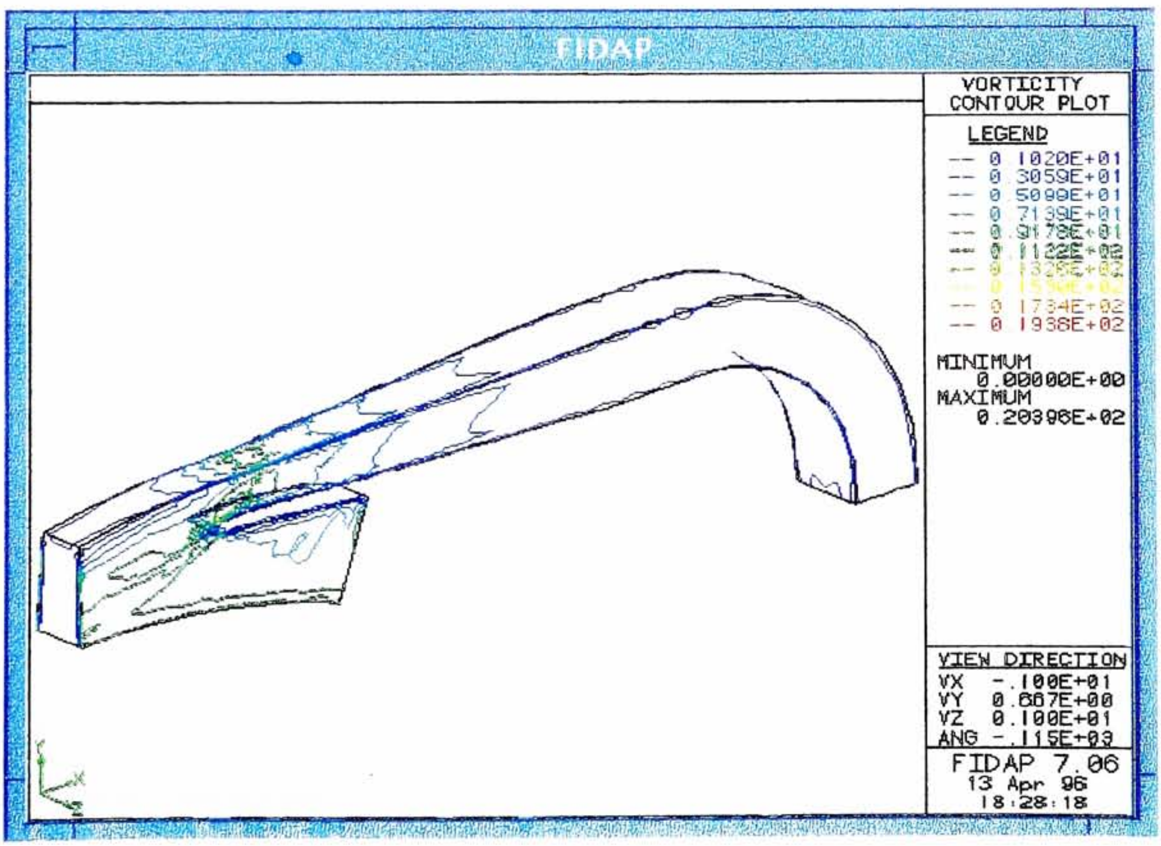


Figure 102 - Vorticity Contour Plot (60% - 7%)

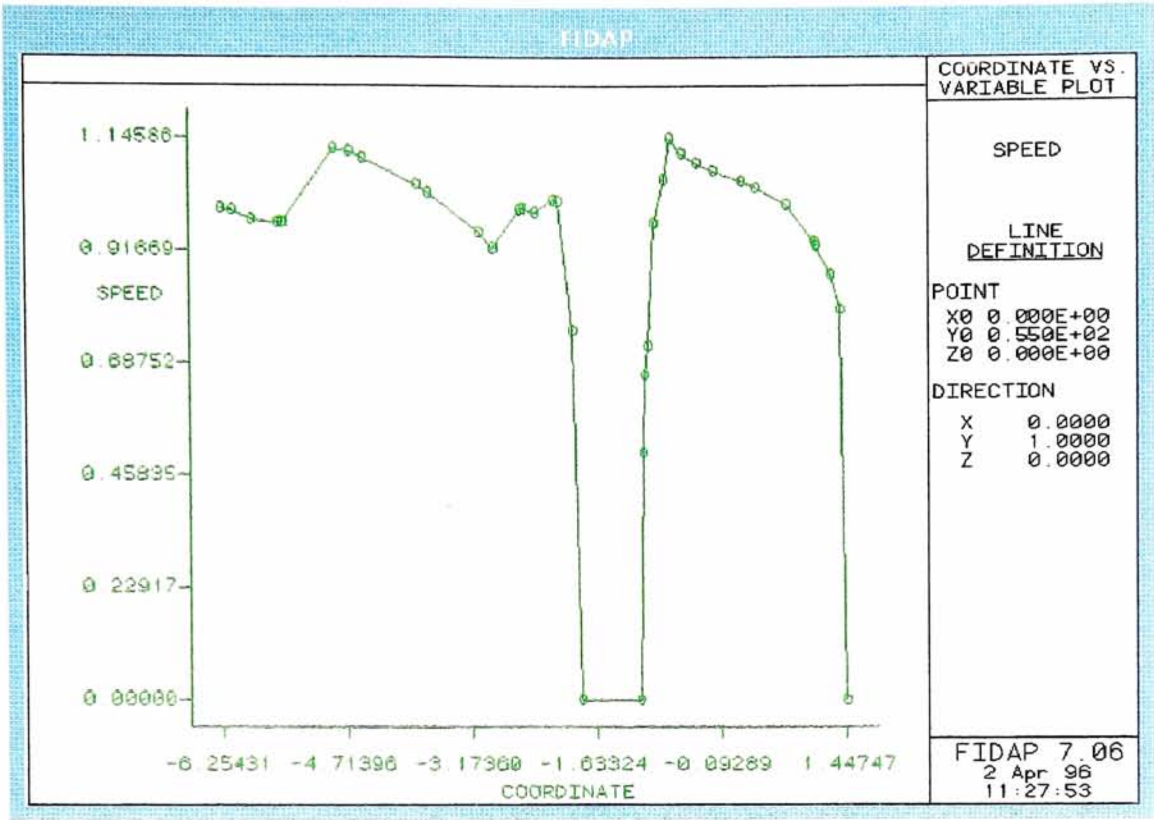


Figure 103 - Inlet Velocity Profile (60% - 7%)

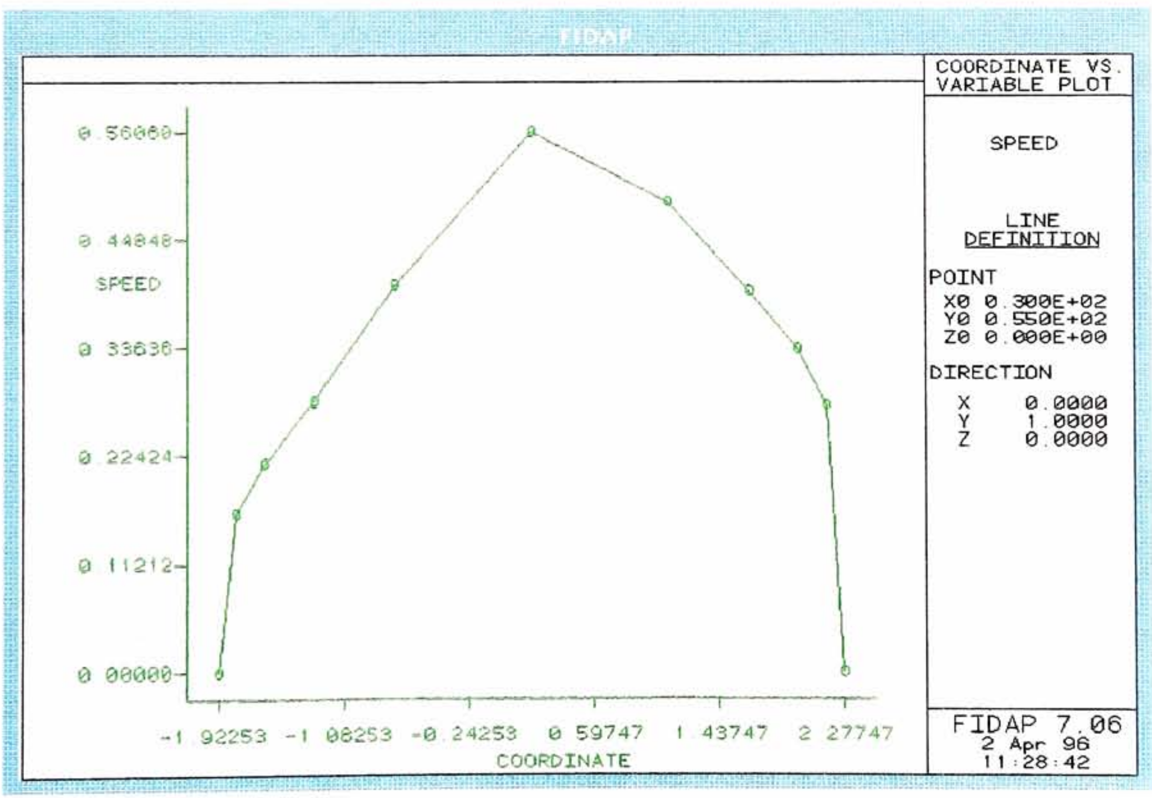


Figure 104 - Outlet Velocity Profile (60% - 7%)

7.4.3. 60% - 10% Flow Case.

The injection rate of 10% of the inlet mass flow rate through the six slits at an angle of 35 degrees, relative to the diffuser centerline, resulted in the application of a horizontal component of 0.0259 and a vertical component of 0.0182 as boundary conditions at the fluid injection slits (Refer to Appendix A for the calculations).

The velocity vector plot on the symmetry plane (Figure 105) shows that there is flow separation all along the bottom plane of the diffuser. The same phenomenon can be seen in the shroud side plane (Figure 106) and on the bottom plane (Figure 107), which are the same planes used to study the other cases. The perpendicular views of the shroud side plane (Figure 108) and the bottom plane (Figure 111) also show the effects of flow separation. The effect of the injected fluid can be seen on the close ups of the shroud side. The first one (Figure 109) shows how the fluid is being injected into the diffuser and accelerates the particles that are starting to slow down near the wall. It is important to notice how the elevated amount of fluid injection breaks the boundary layer in the bottom plane and increases the amount of separation in the diffuser. The second close up (Figure 110) shows the behavior of the fluid in the diffuser. It can be seen how the amount of separation increases as we go along the diffuser and also how the flow is beginning to separate in the top plane of the diffuser. This is a phenomenon that we will be able to see more clearly when we analyze the 20%-10% flow case. The same behavior can be observed in the perpendicular view of the velocity vector on the bottom plane (Figure 111). A close up of this case was made to verify these results (Figure 112).

As it was shown in previous cases, flow separation also was found in the diffuser's vaneless region in the shroud side (Figure 113). Secondary flow effects are responsible for the creation of this area of flow separation. The pressure contour plot (Figure 114) shows the little pressure recovery taking place in the diffuser. The pressure along the centerline (Figure 115) indicates a relatively uniform conversion of dynamic head to static pressure as the diffuser is traversed in the direction of flow. Using the pressure line plots from the bottom of the diffuser to the top, at the diffuser inlet (Figure 116) and outlet (Figure 117), the pressure recovery coefficient was calculated to be 0.5518. From these results it is obvious that the increase in the amount of fluid being injected affected considerably the performance of the diffuser. The large amount of fluid injected creates a pocket of flow separation even bigger than the one that was observed in the 20% of design flow case.

The kinetic energy (Figure 118), dissipation (Figure 119), and vorticity (Figure 120) contour plots are included for flow verification. The majority of the kinetic energy is generated at the diffuser's entrance region on both the top and bottom planes near the shroud side wall, with a corresponding amount of dissipation in the same area. The vorticity, which is an indication of the level of viscosity present in the fluid at a particular location, shows also this behavior. This could be caused by the injection of fluid in this part of the diffuser. The velocity profiles that were graphed at positions near the diffuser inlet (Figure 121) and outlet (Figure 122) of the diffuser on the symmetry plane and are typical of turbulent flow in a diffuser. The inlet velocity profile shows the flow separation that occurs in the entrance to the vaneless section and the outlet velocity profile shows the significant reduction in the flow speed that is present in the diffuser's bottom plane near the shroud side.

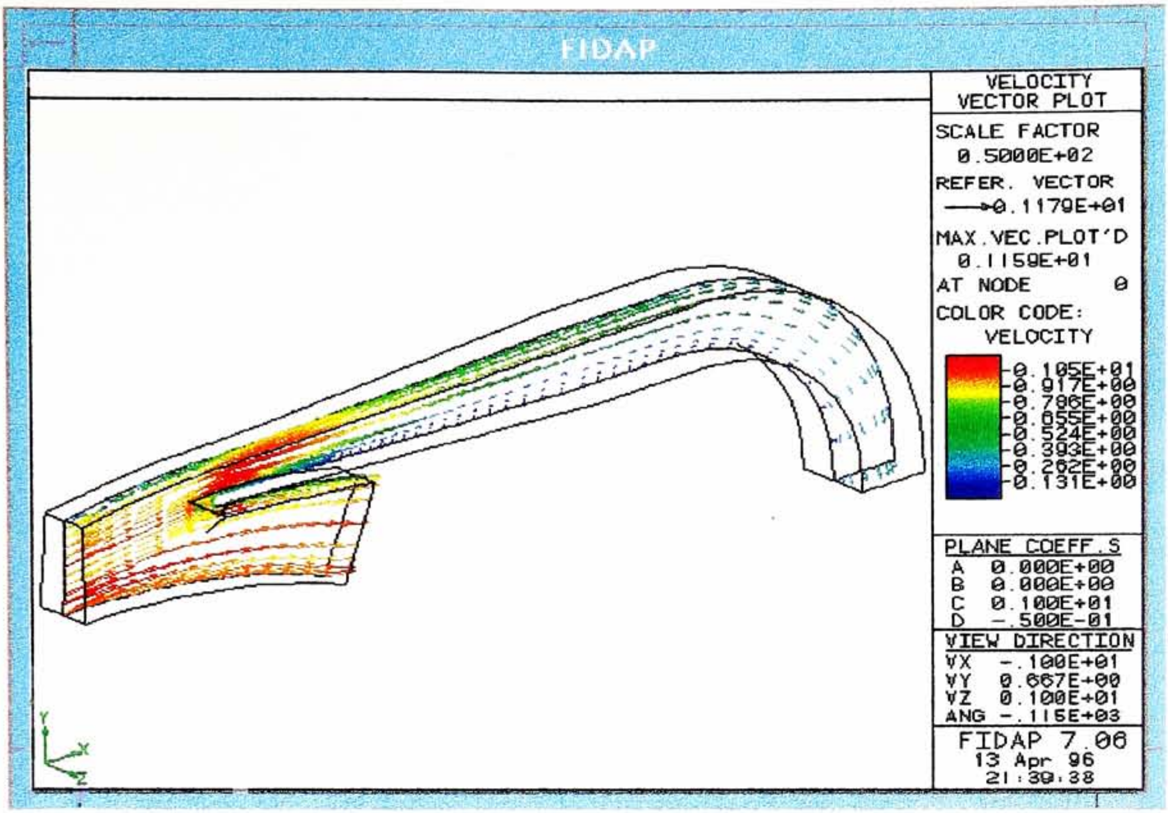


Figure 105 - Velocity on Symmetry Plane (60% - 10%)

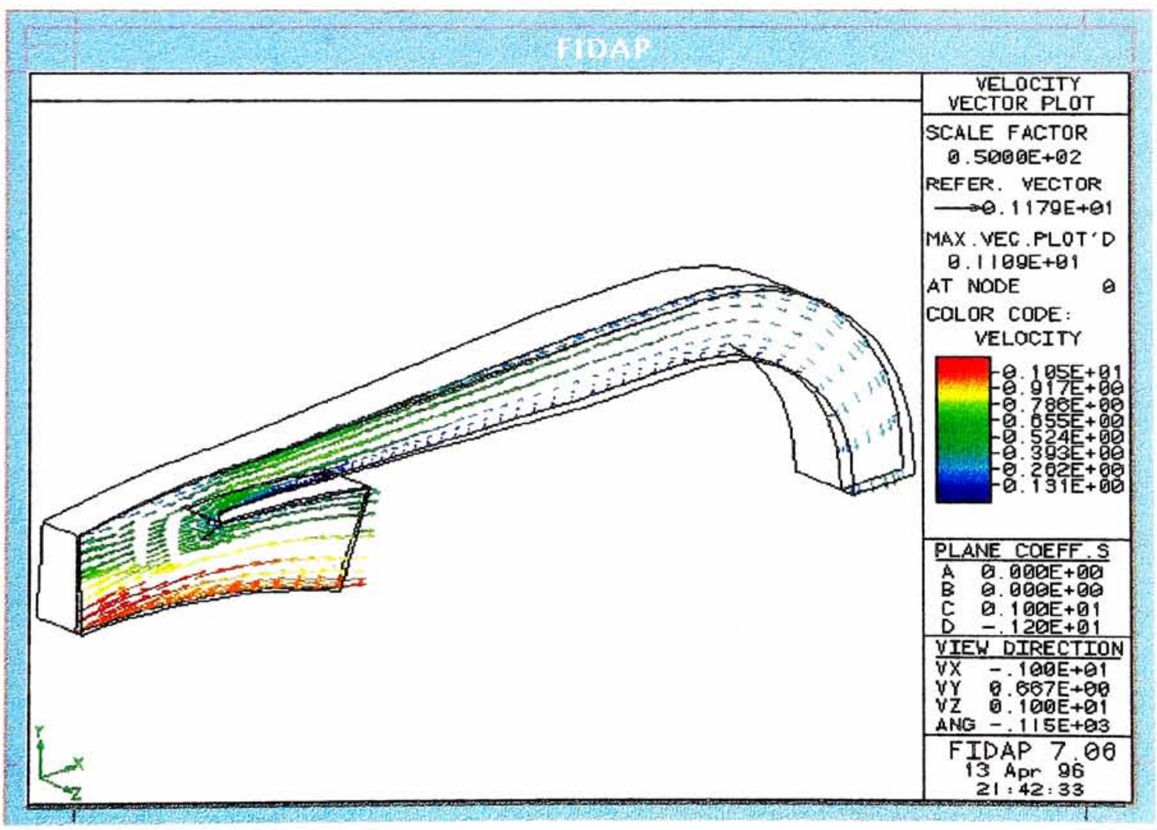


Figure 106 - Velocity on Shroud Side Plane (60% - 10%)

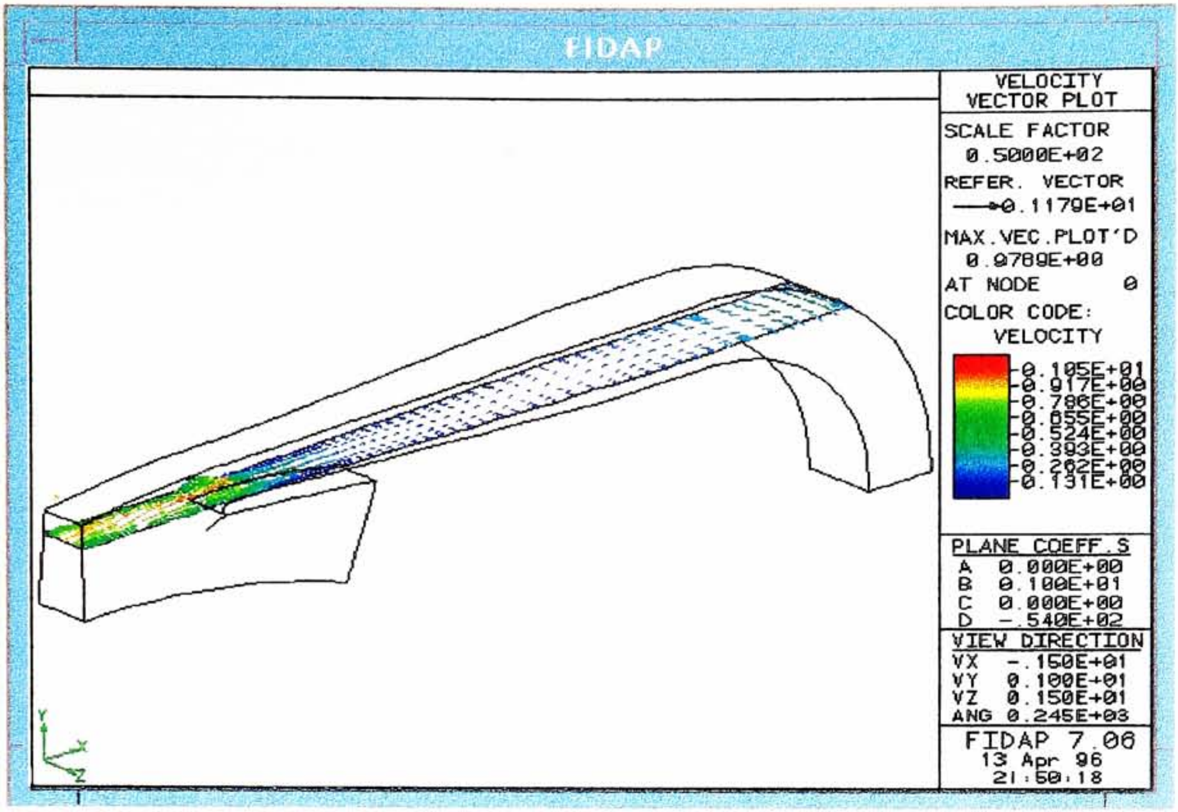


Figure 107 - Velocity on Bottom Plane (60% - 10%)

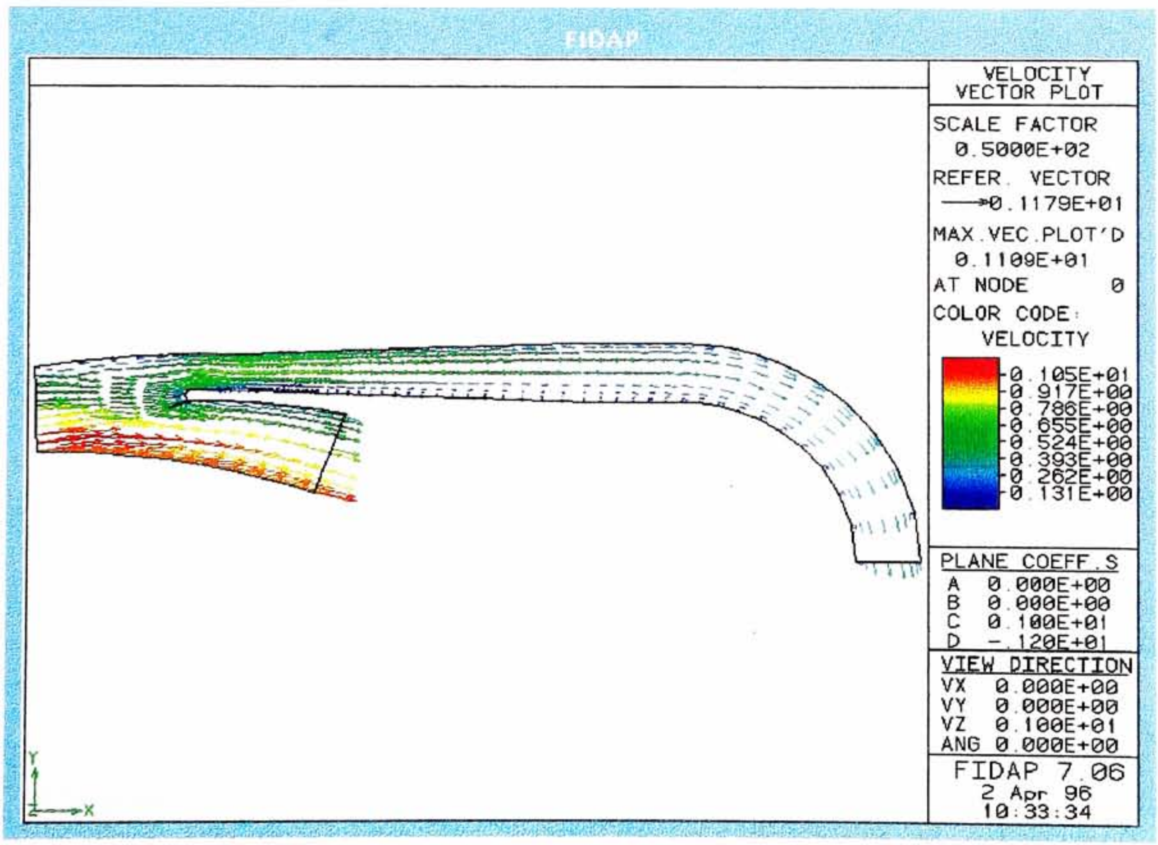


Figure 108 - 2-D View of Velocity on Shroud Side (60% - 10%)

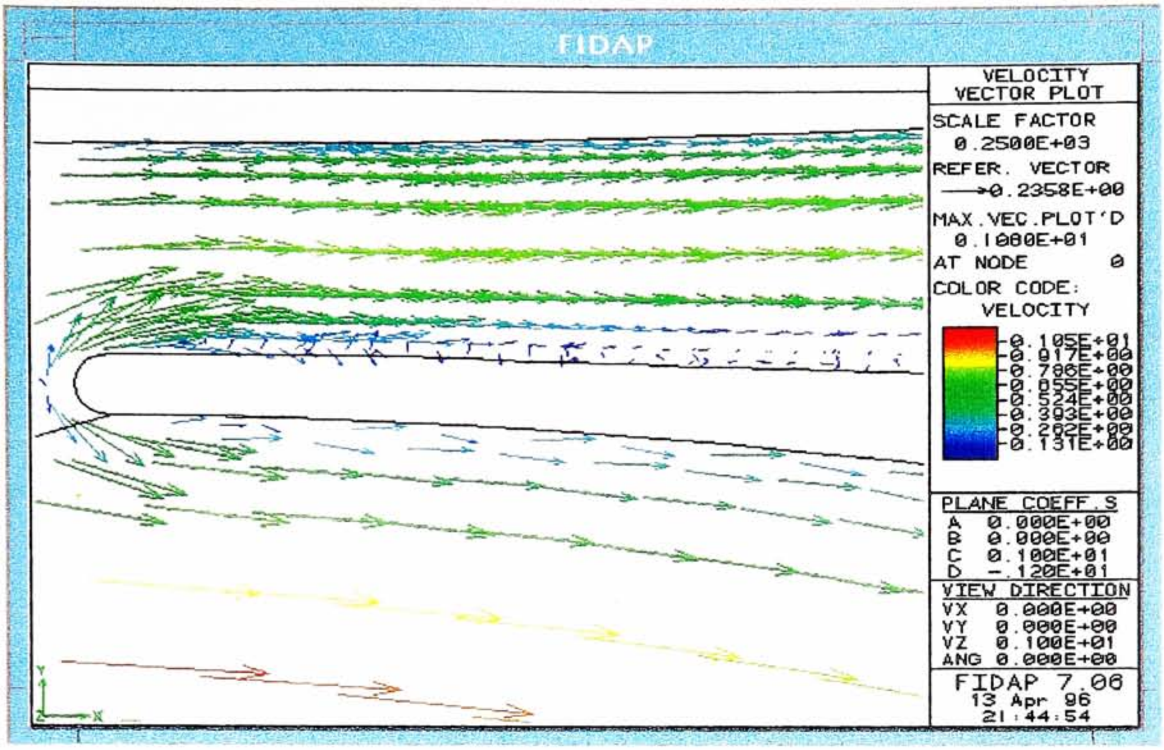


Figure 109 - Velocity's at Diffuser Inlet on Shroud Side (60%-10%)

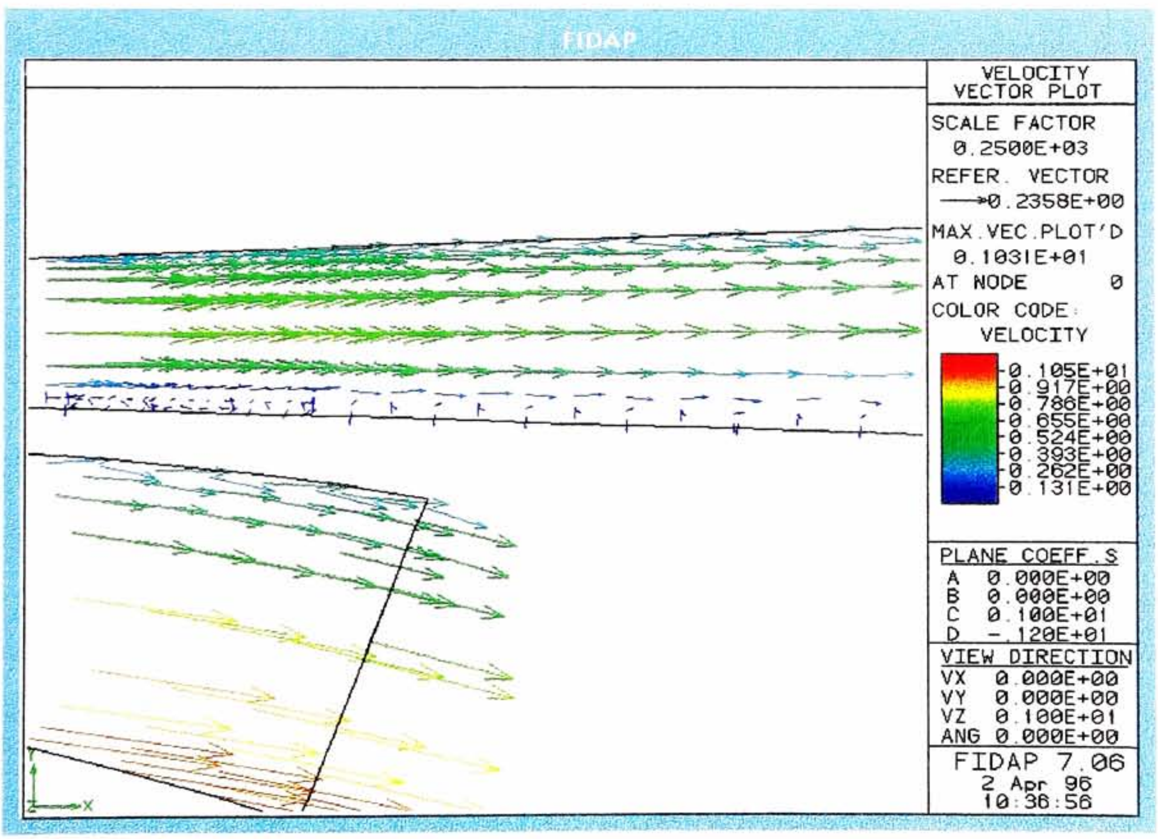


Figure 110 - Velocity at Diffuser's Throat on Shroud Side (60% - 10%)

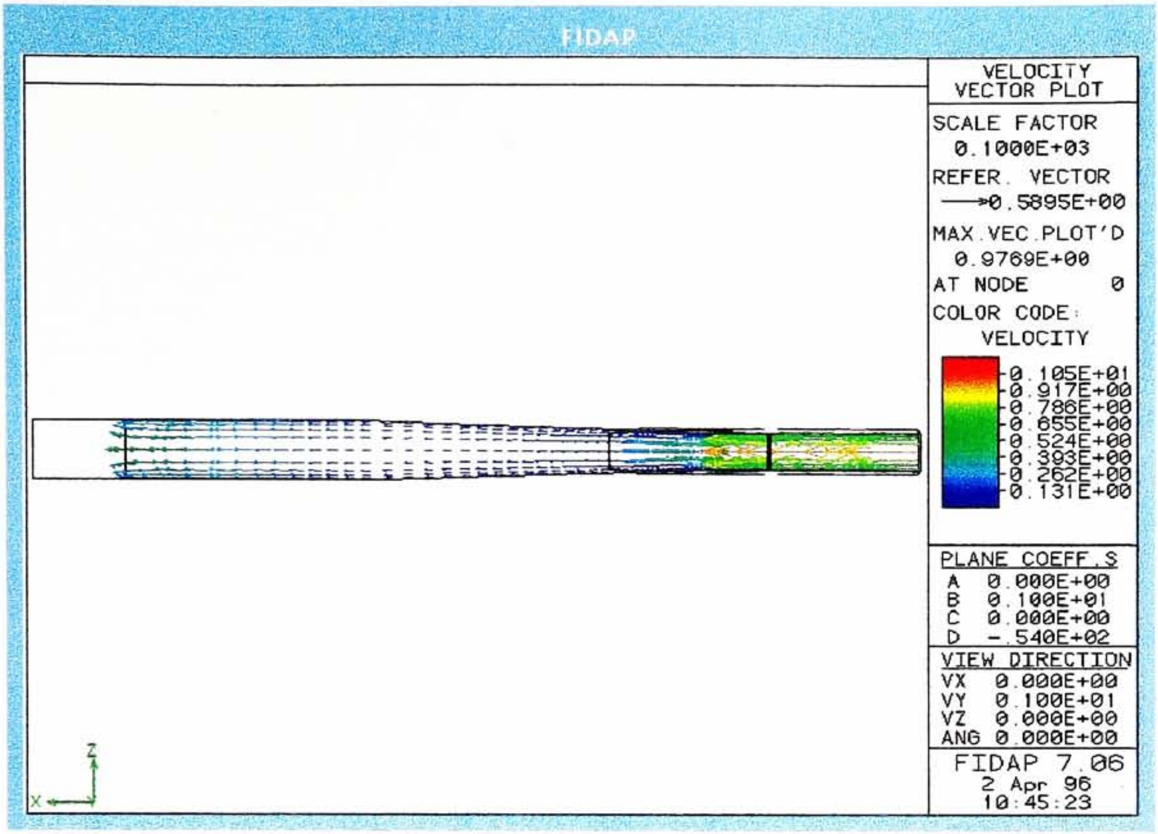


Figure 111 - 2-D View of Velocity on Bottom (60% - 10%)

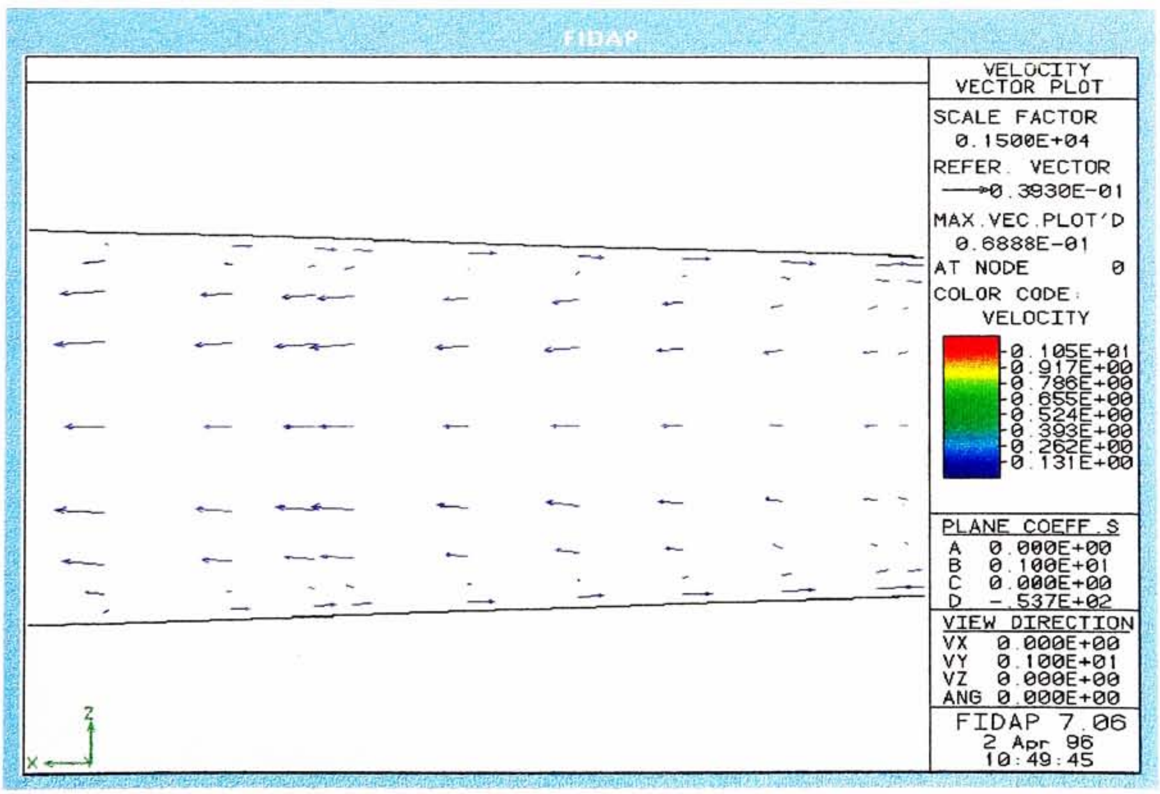


Figure 112 - Velocity at Outlet on Bottom (60% - 10%)

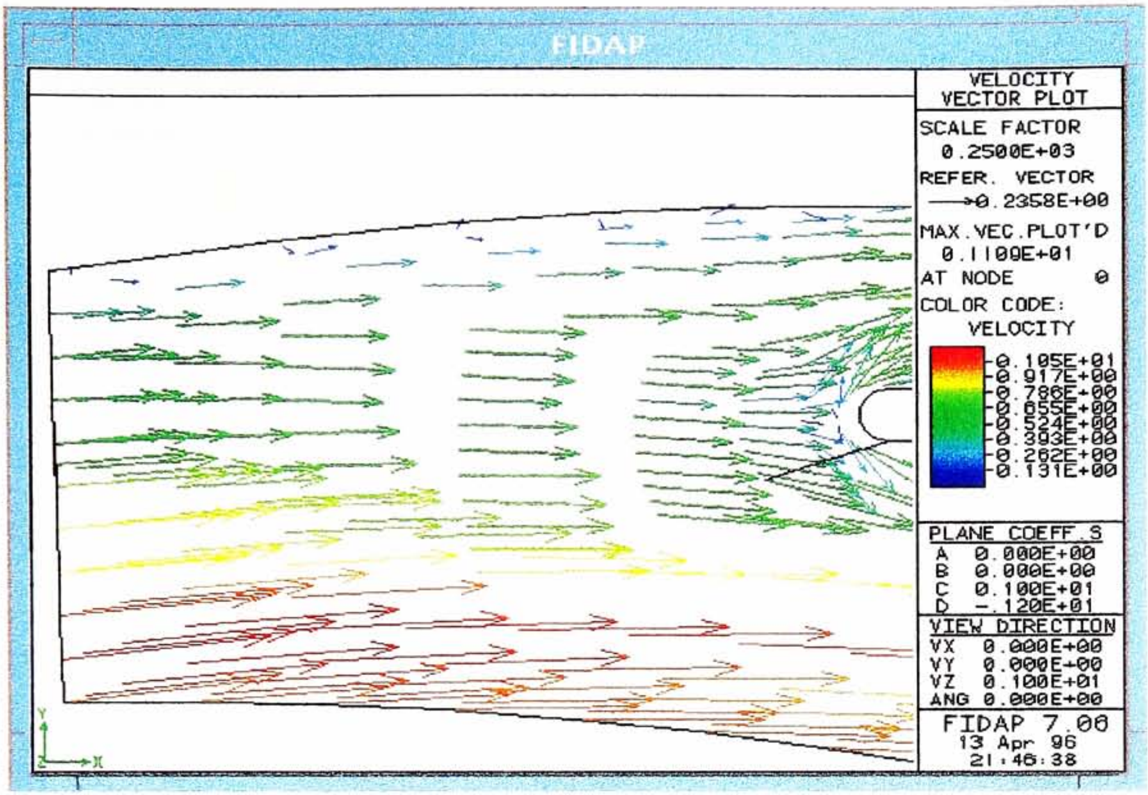


Figure 113 - Close Up on Shroud Side at the Inlet (60%-10%)

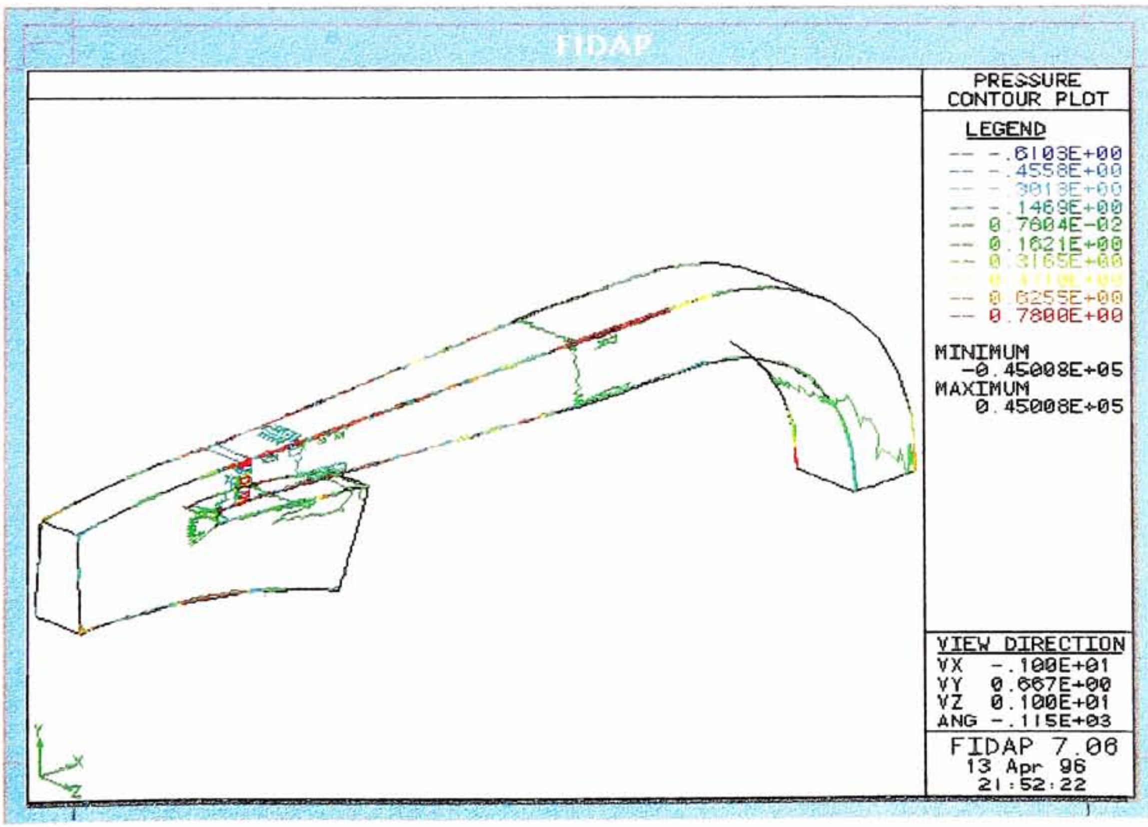


Figure 114 - Pressure Contour Plot (60% - 10%)

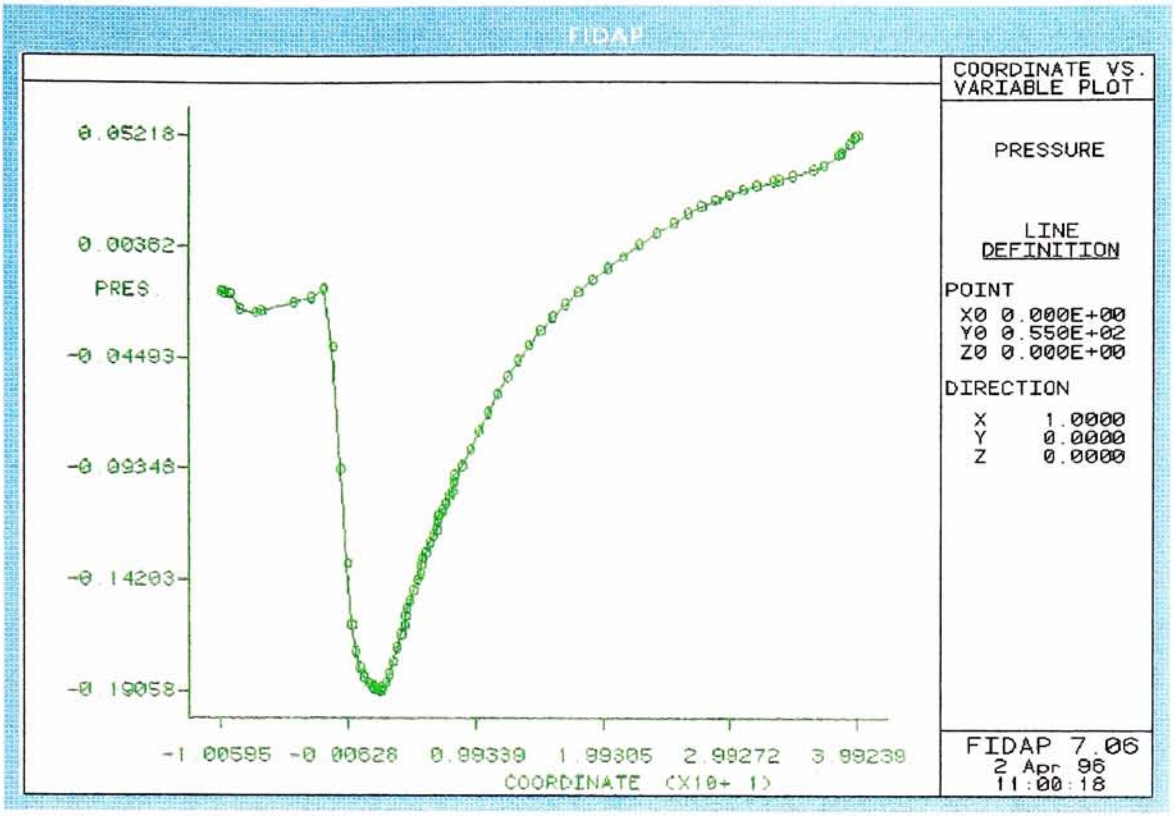


Figure 115 - Pressure Along the Centerline (60% - 10%)

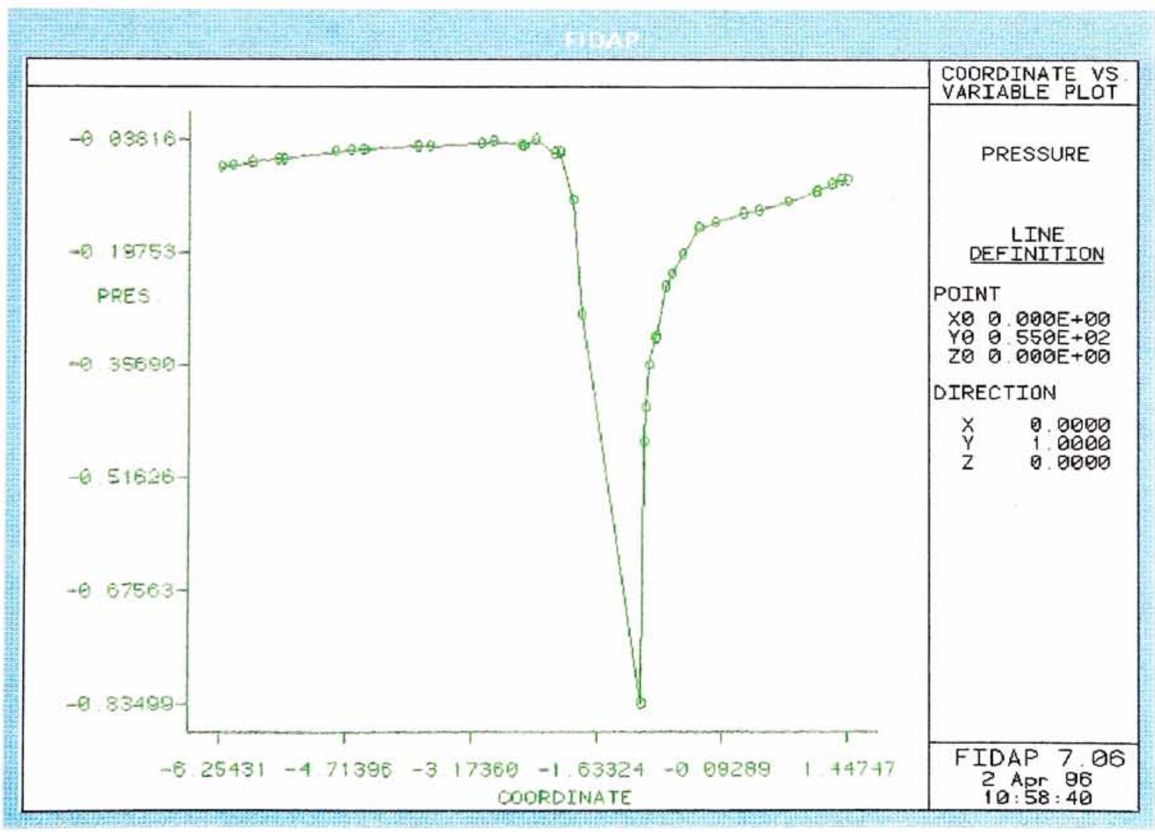


Figure 116 - Inlet Pressure (60% - 10%)

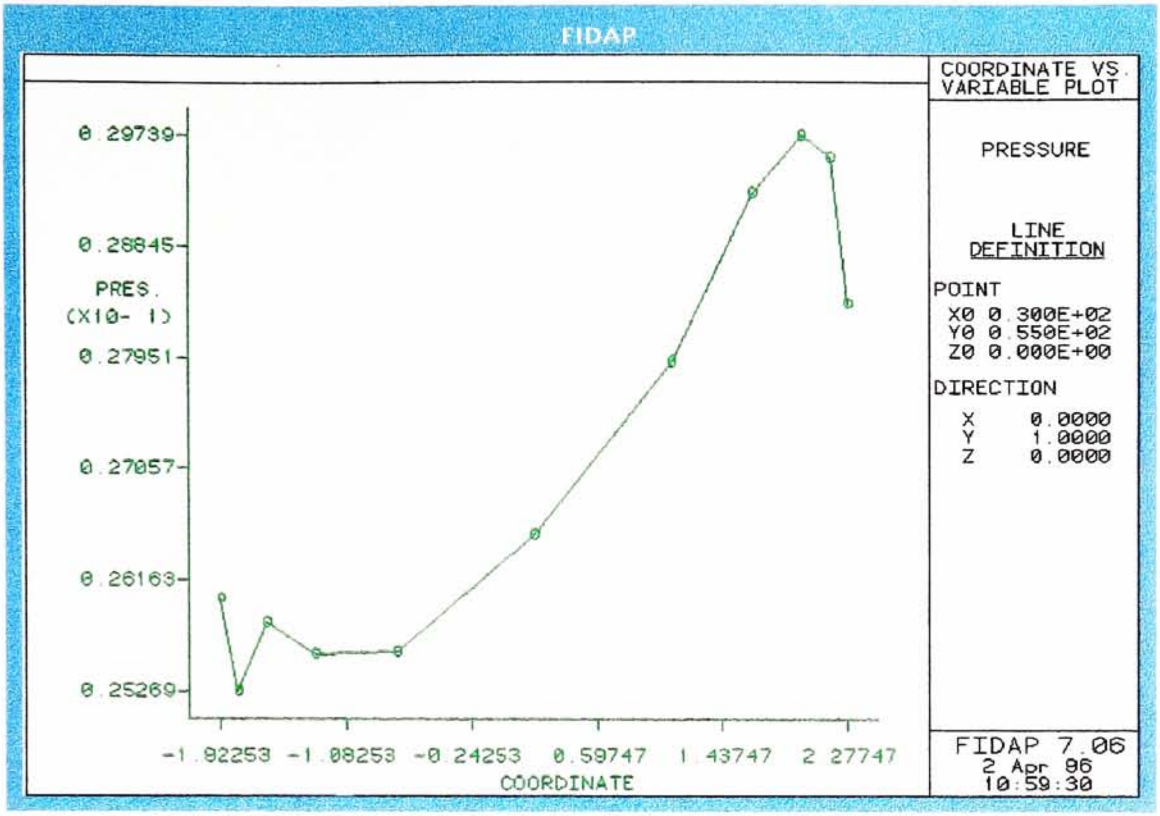


Figure 117 - Outlet Pressure (60% - 10%)

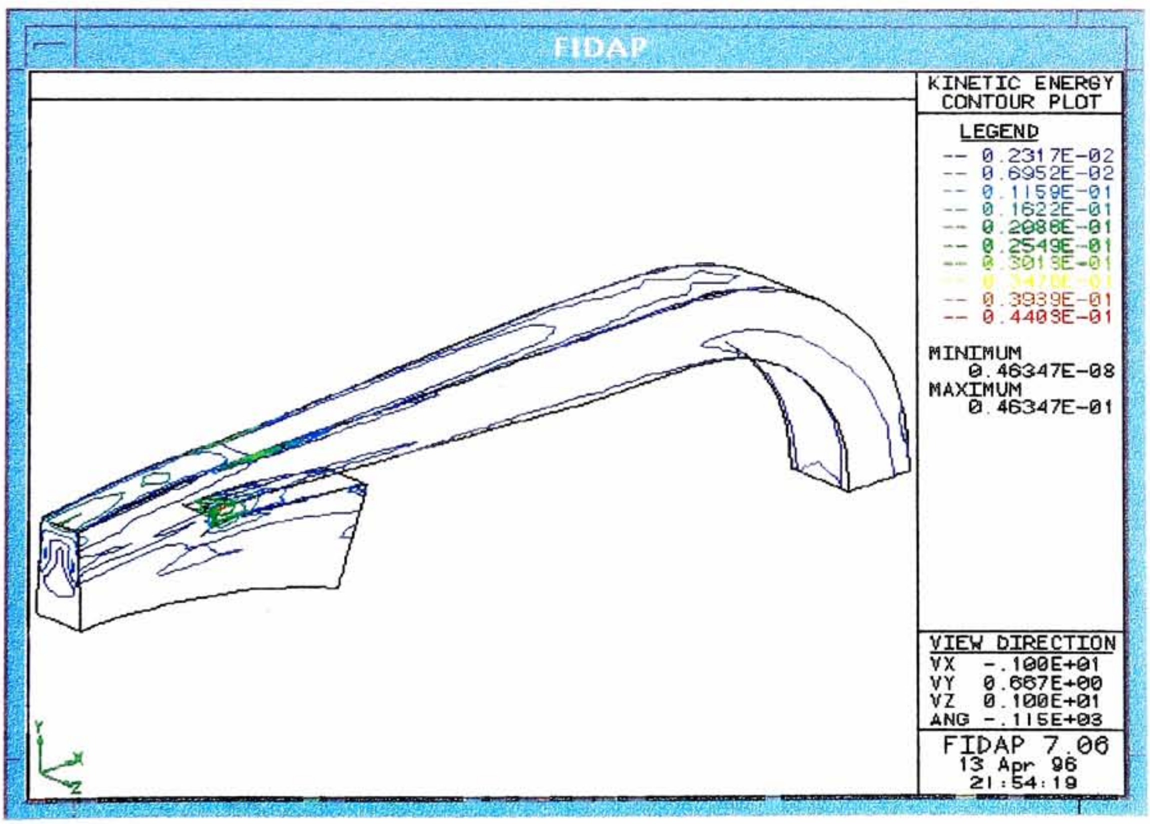


Figure 118 - Kinetic Energy Contour Plot (60% - 10%)

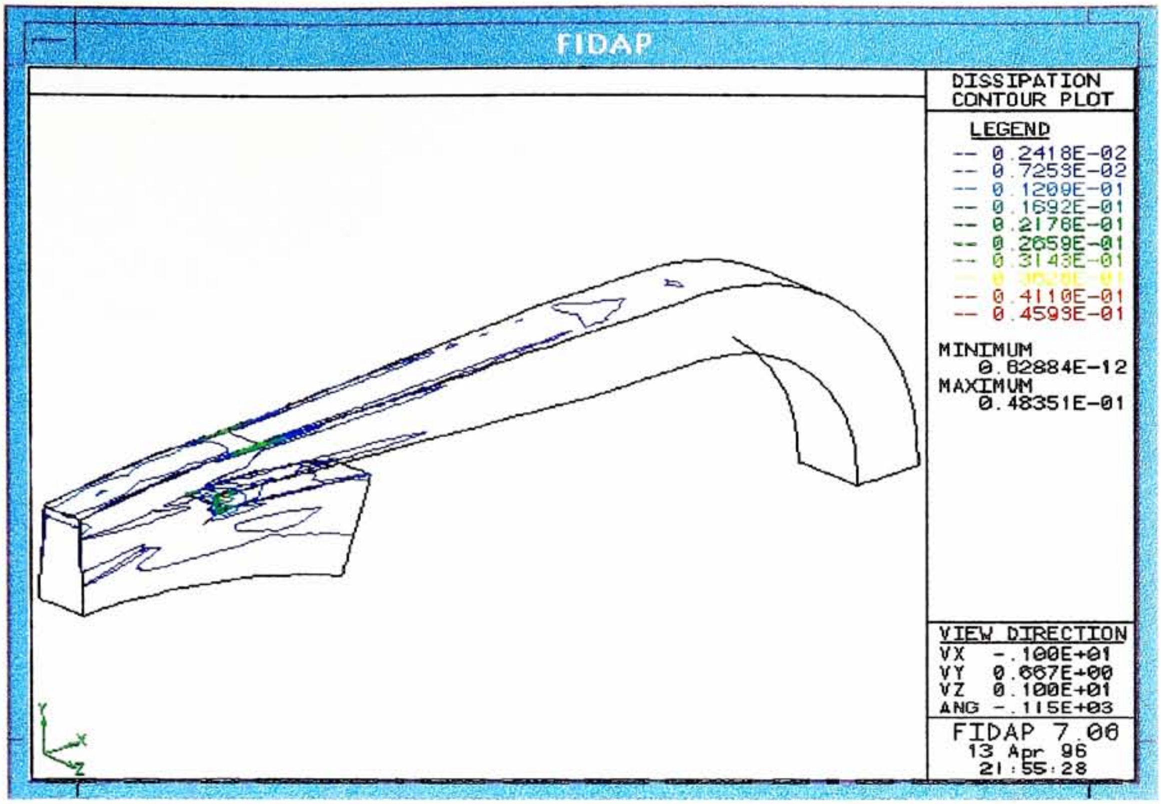


Figure 119 - Dissipation Contour Plot (60% - 10%)

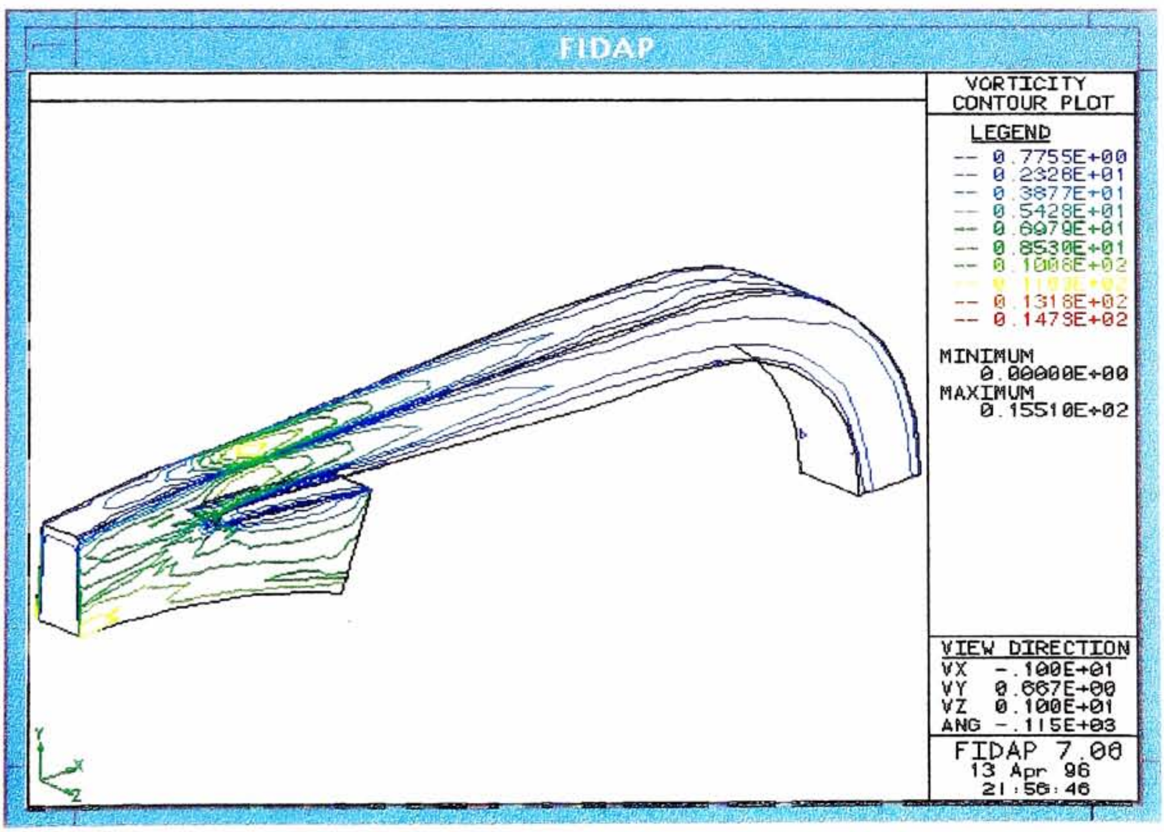


Figure 120 - Vorticity Contour Plot (60% - 10%)

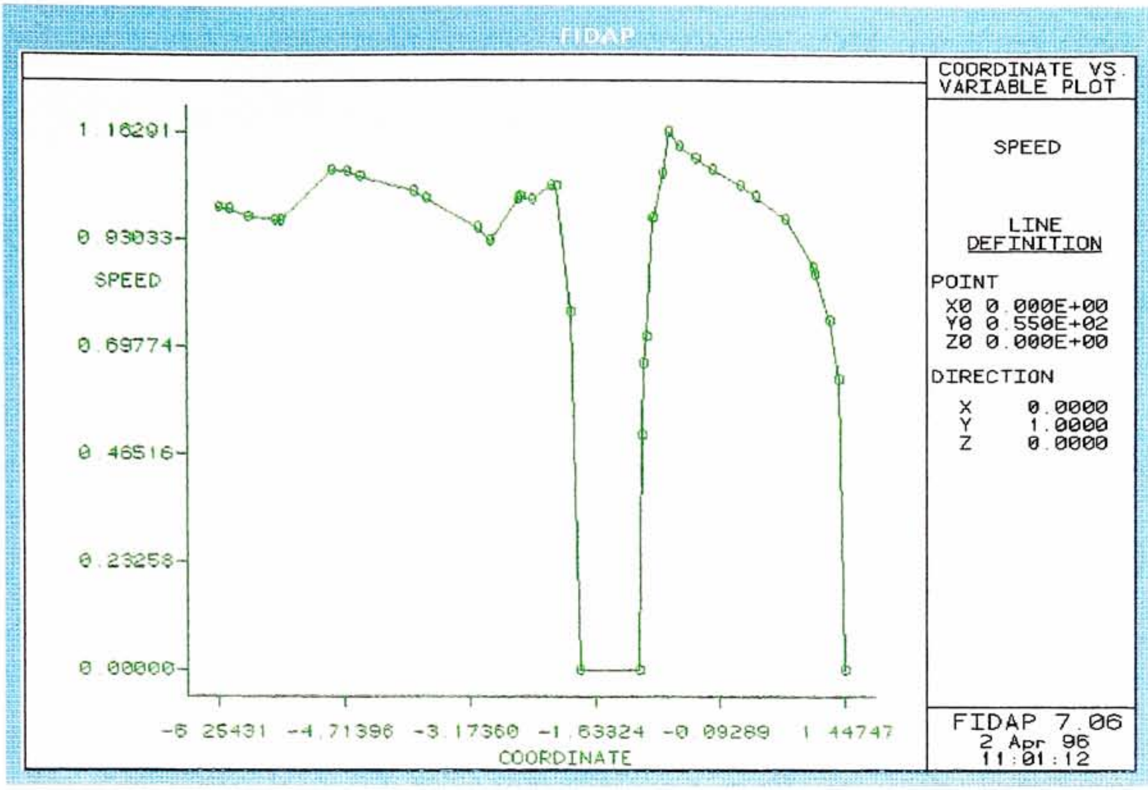


Figure 121 - Inlet Velocity Profile (60% - 10%)

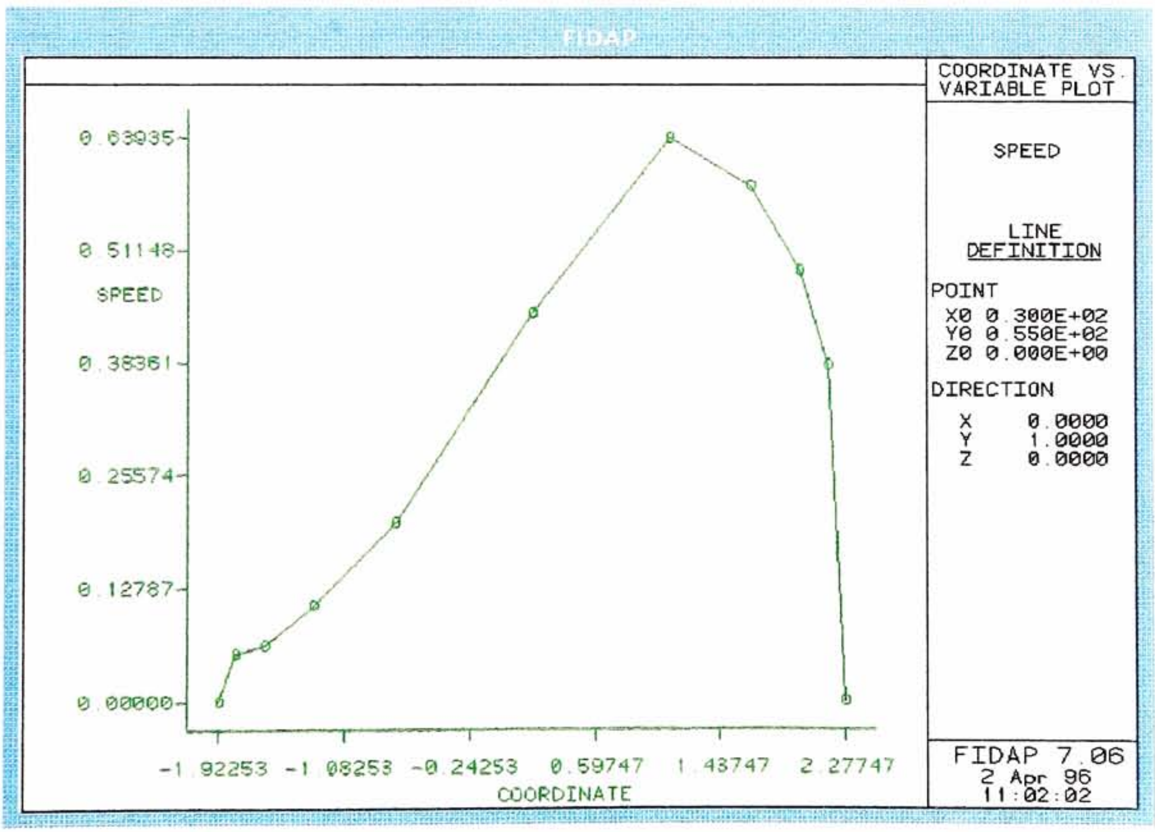


Figure 122 - Outlet Velocity Profile (60% - 10%)

7.4.4. 20% - 3% Flow Case.

The purpose of this case is to study the effect of fluid injection at low flow rates. The injection rate of 3% of the inlet mass flow rate through the six slits at an angle of 35 degrees, relative to the diffuser centerline, resulted in the application of a horizontal component of 0.0079 and a vertical component of 0.005459 as boundary conditions at the fluid injection slits (Refer to Appendix A for the calculations).

The velocity vector plot on the symmetry plane (Figure 123) shows that there is no separation although there is an area of flow retardation at the diffuser's outlet. The same phenomenon can be seen in the shroud side plane (Figure 124) and on the bottom plane (Figure 125), which are the same planes used before to observe the area of maximum flow separation. The perpendicular views of the shroud side plane (Figure 126) and the bottom plane (Figure 129) also show no sign of flow separation. The effect of the injected fluid can be seen on the close ups of the shroud side. The first one (Figure 127) shows how the fluid is being injected into the diffuser and accelerates the particles that are starting to slow down near the wall. The second close up (Figure 128) shows the behavior of the fluid in the diffuser and once again it can be seen that there is no flow separation anywhere in the diffuser although the fluid slows down in the bottom plane of the diffuser when it gets close to the outlet. The same behavior can be observed in the perpendicular view of the velocity vector on the bottom plane (Figure 129). A close up of this case was made to verify these results (Figure 130).

Flow separation also was found in the shroud side of the vaneless region (Figure 131). Secondary flow effects are probably the responsible for the creation of this area of flow separation. The pressure contour plot (Figure 132) and the pressure along the centerline (Figure 133) indicate a relatively uniform conversion of dynamic head to static pressure as the diffuser is traversed in the direction of flow. Using the pressure line plots from the bottom of the diffuser to the, at the diffuser inlet (Figure 134) and outlet (Figure 135), the pressure recovery coefficient was calculated to be 0.61. This value shows a significant improvement with respect to the value obtained, 0.50, with the 20% off design flow case.

The kinetic energy (Figure 136), dissipation (Figure 137), and vorticity (Figure 138) contour plots are included for flow verification. The majority of the kinetic energy is generated at the diffuser's entrance region on both the top and bottom planes near the shroud side wall, with a corresponding amount of dissipation in the same area. The vorticity, which is an indication of the level of viscosity present in the fluid at a particular location, shows also this behavior. This could be caused by the injection of fluid in this part of the diffuser. The velocity profiles that were graphed at positions near the diffuser inlet (Figure 139) and outlet (Figure 140) of the diffuser on the symmetry plane and are typical of turbulent flow in a diffuser. The inlet velocity profile shows the flow separation that occurs in the entrance to the vaneless section and the outlet velocity profile shows the significant reduction in the flow speed that is present in the diffuser's bottom plane near the shroud side.

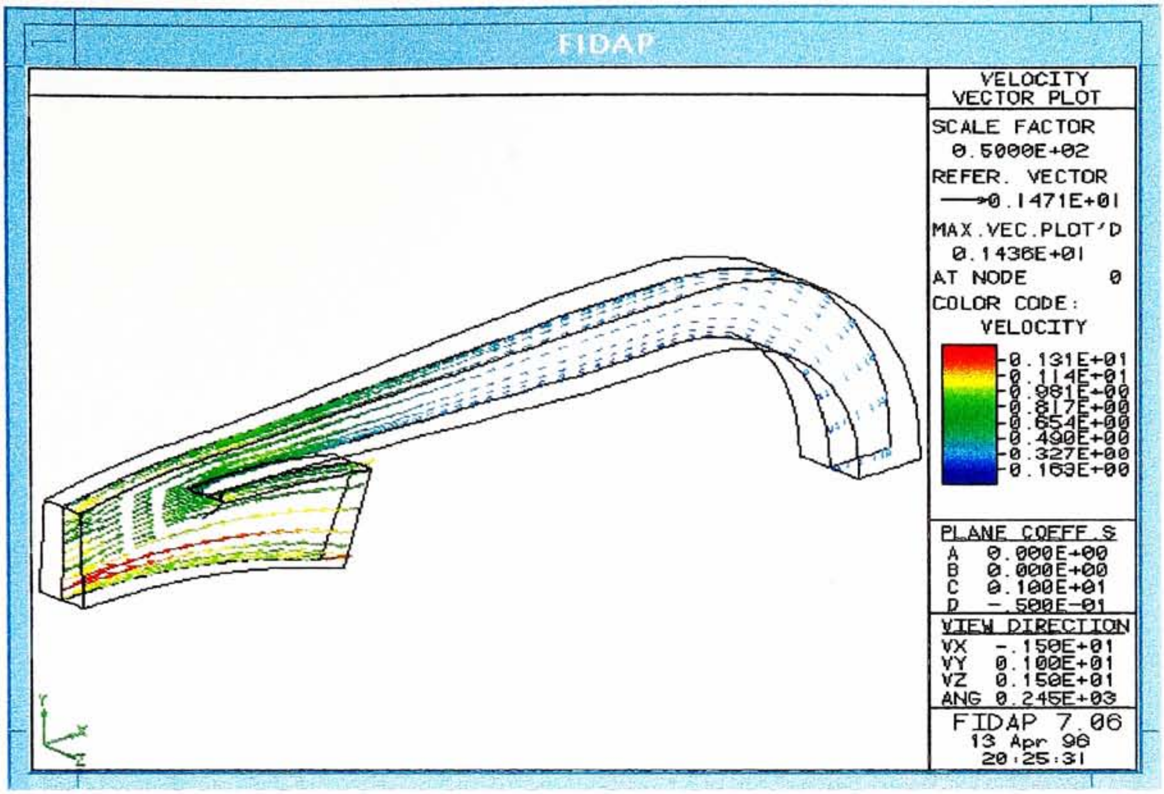


Figure 123 - Velocity on Symmetry Plane (20% - 3%)

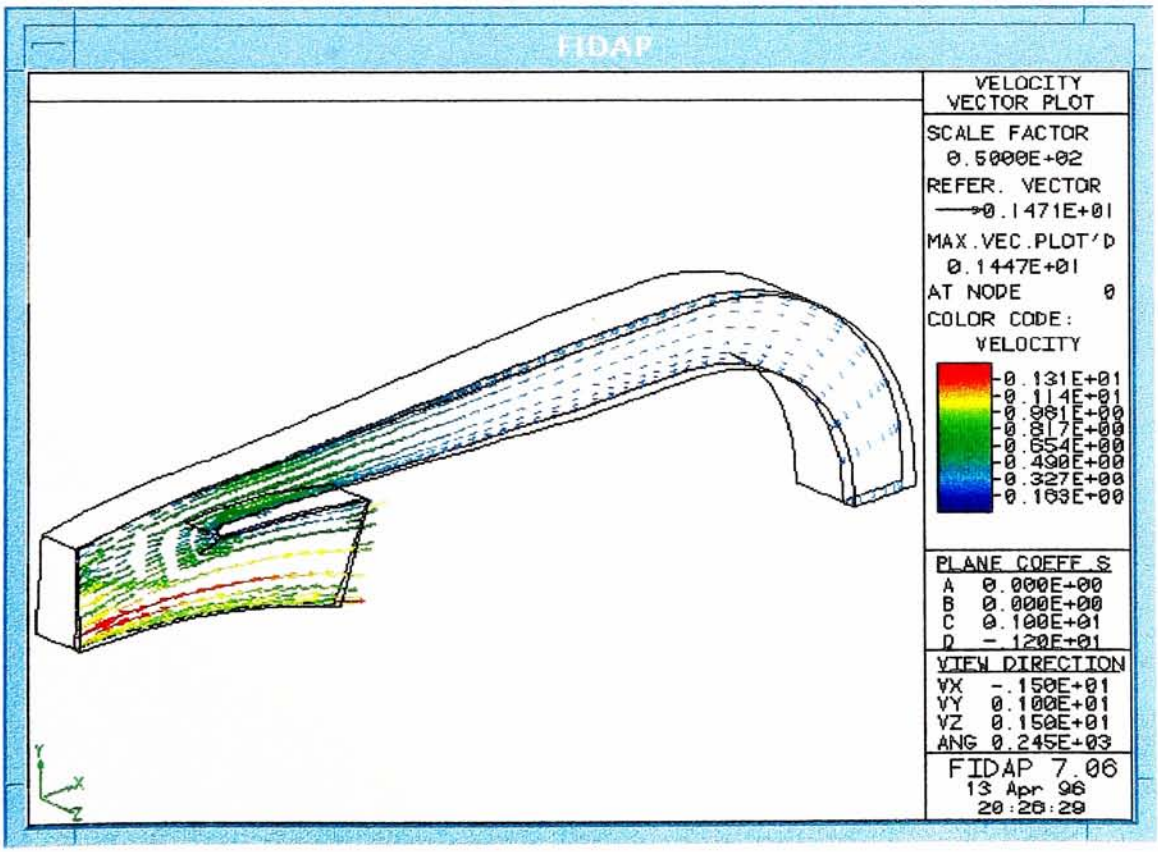


Figure 124 - Velocity on Shroud Side Plane (20% - 3%)

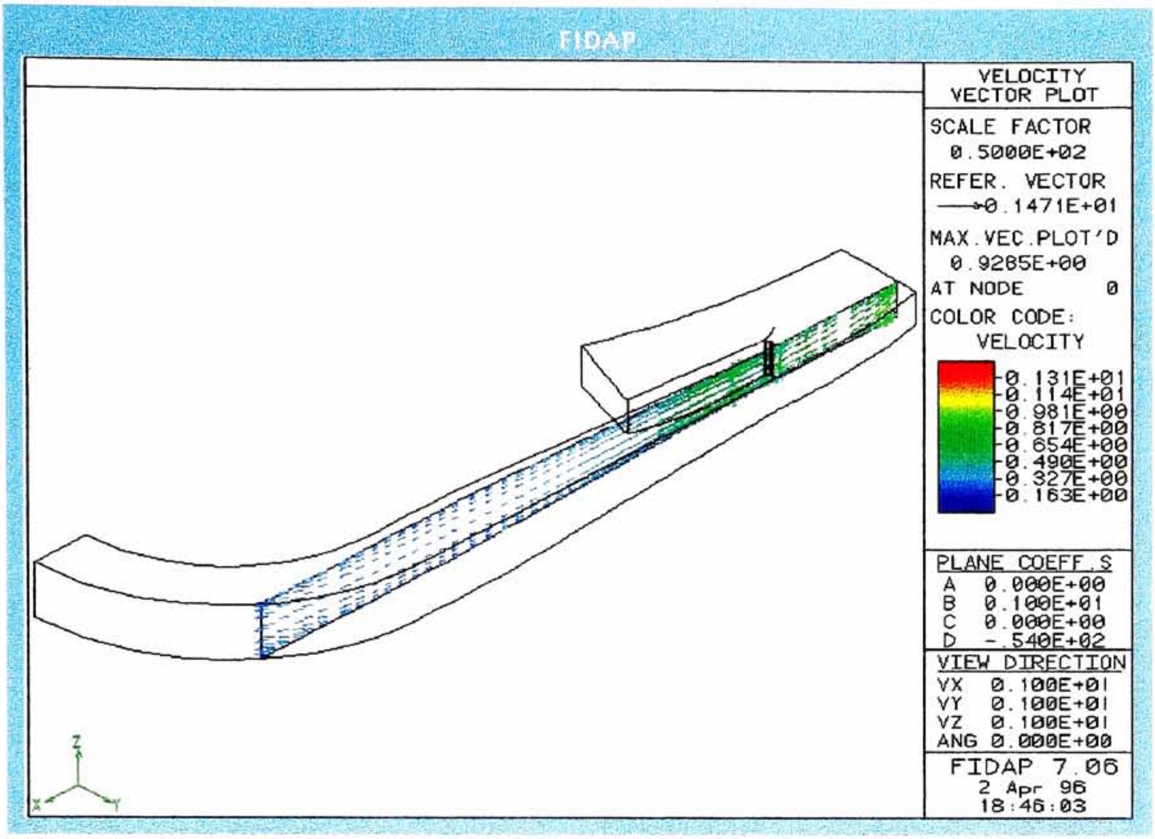


Figure 125 - Velocity on Bottom Plane (20% - 3%)

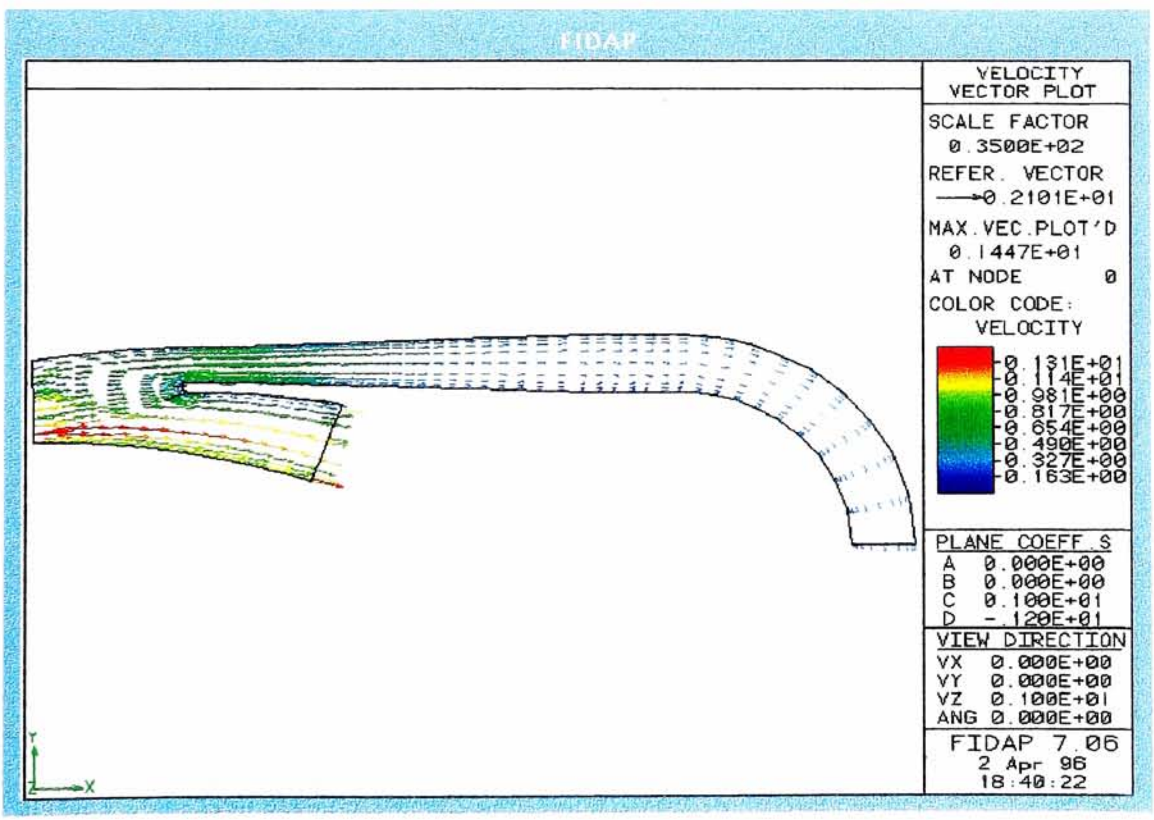


Figure 126 - 2-D View of Velocity on Shroud Side (20% - 3%)

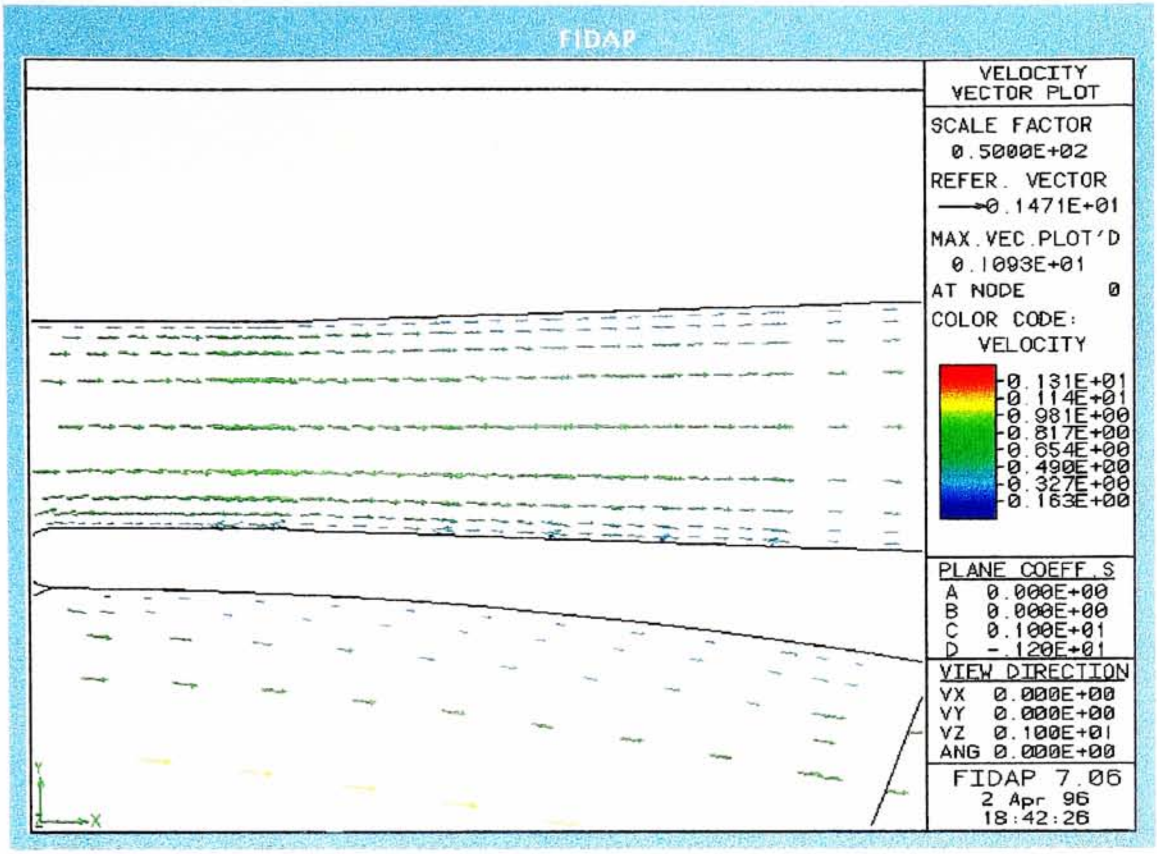


Figure 127 - Velocity at Diffuser's Throat on Shroud Side (20% - 3%)

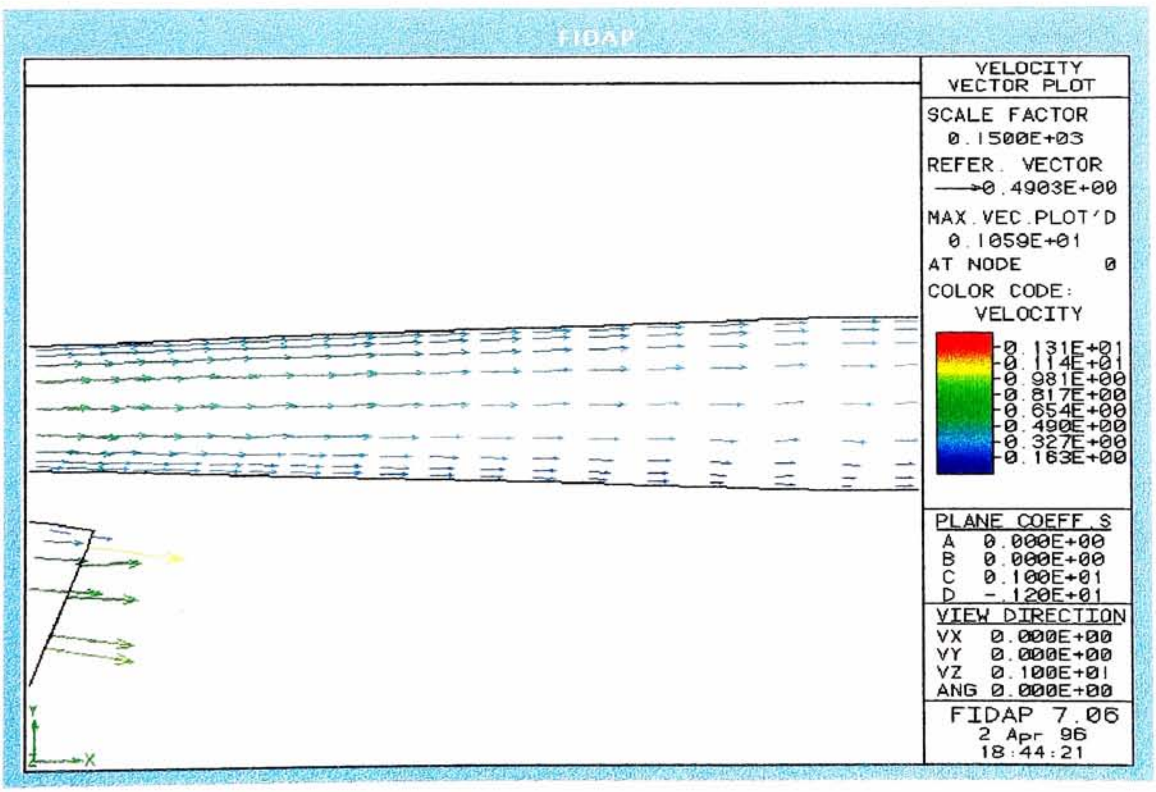


Figure 128 - Velocity at Outlet on Shroud Side (20% - 3%)

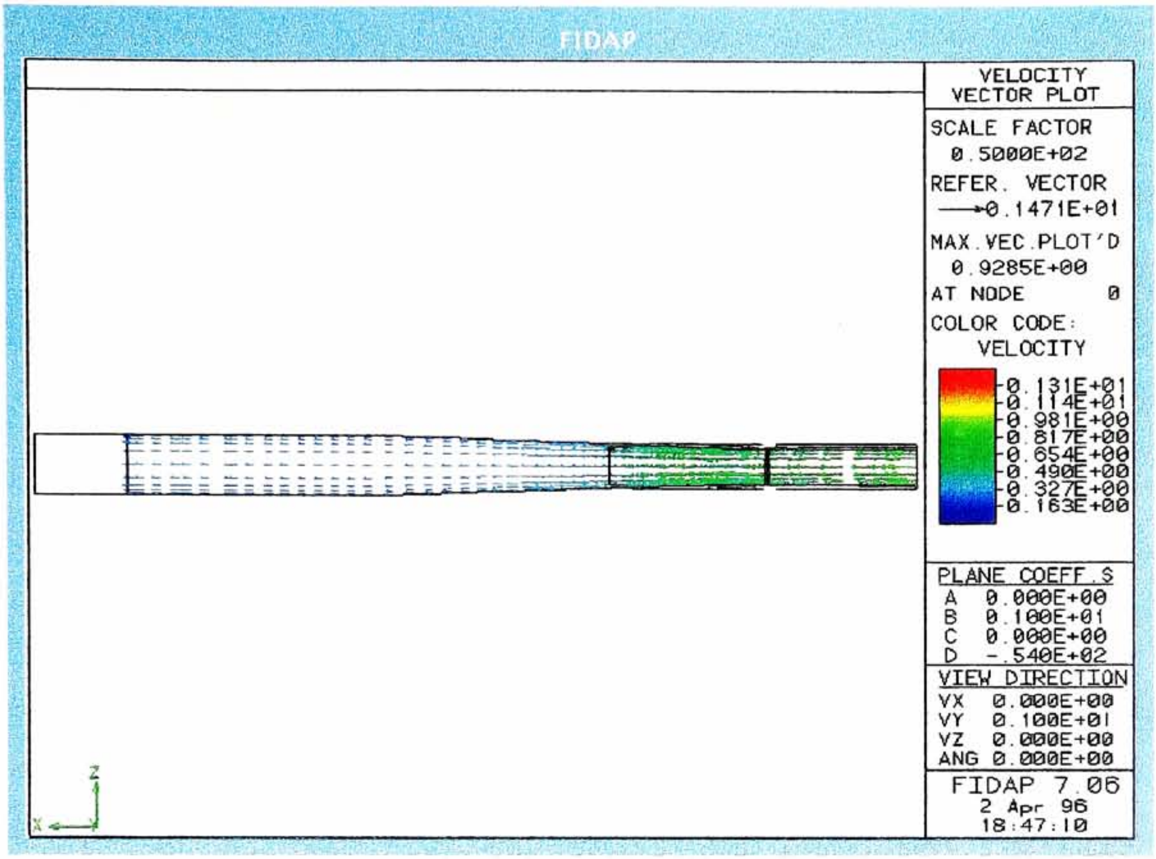


Figure 129 - 2-D View of Velocity on Bottom (20% - 3%)

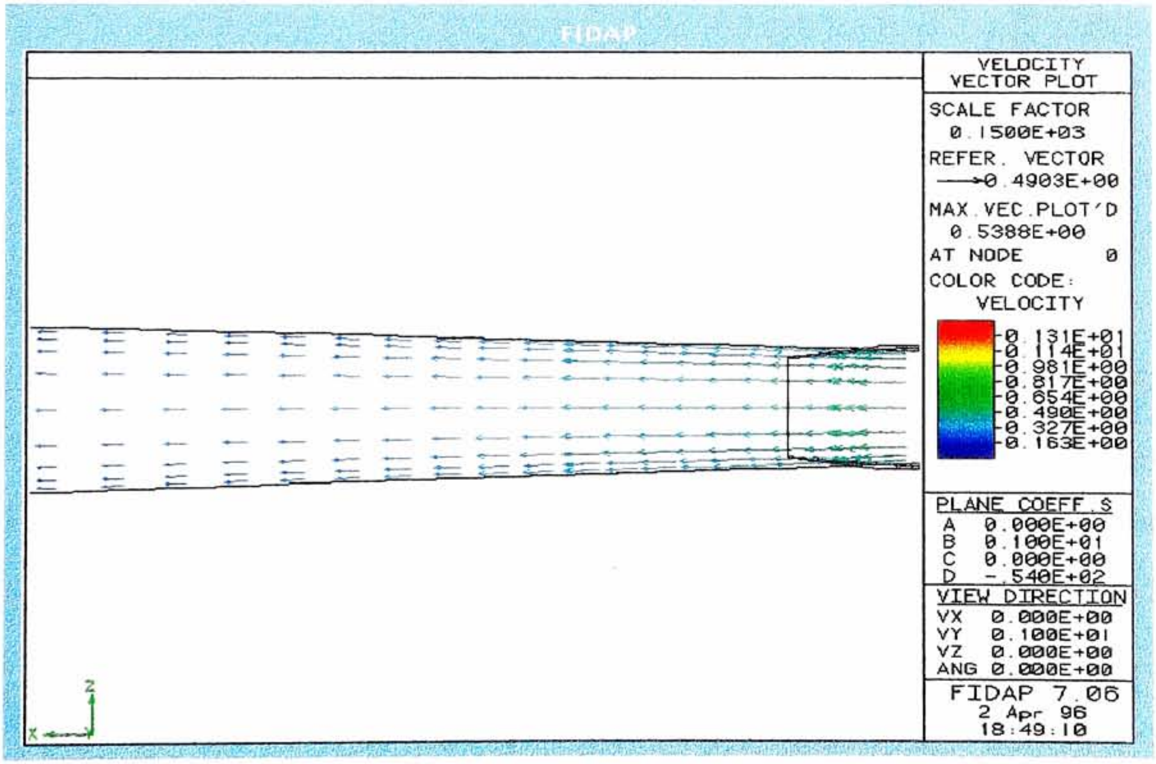


Figure 130 - Close Up of Velocity at Outlet on Bottom (20% - 3%)

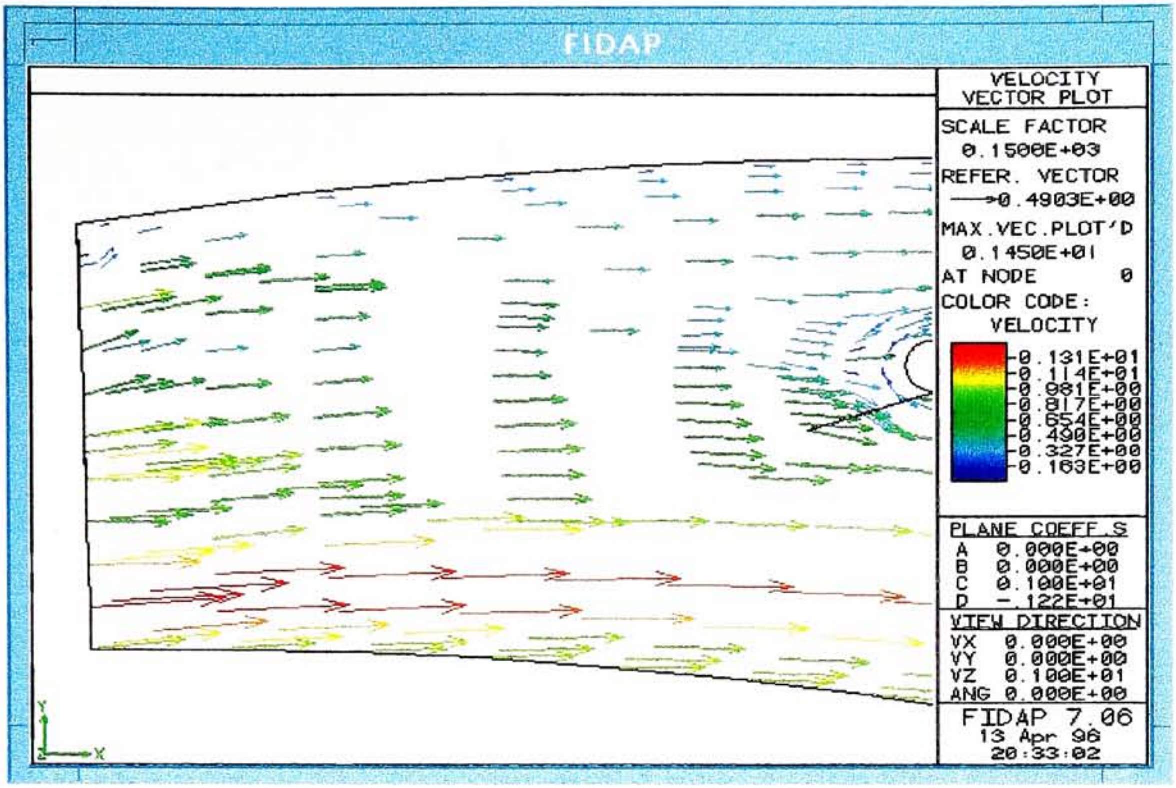


Figure 131 - Velocity at Inlet on Shroud Side (20% - 3%)

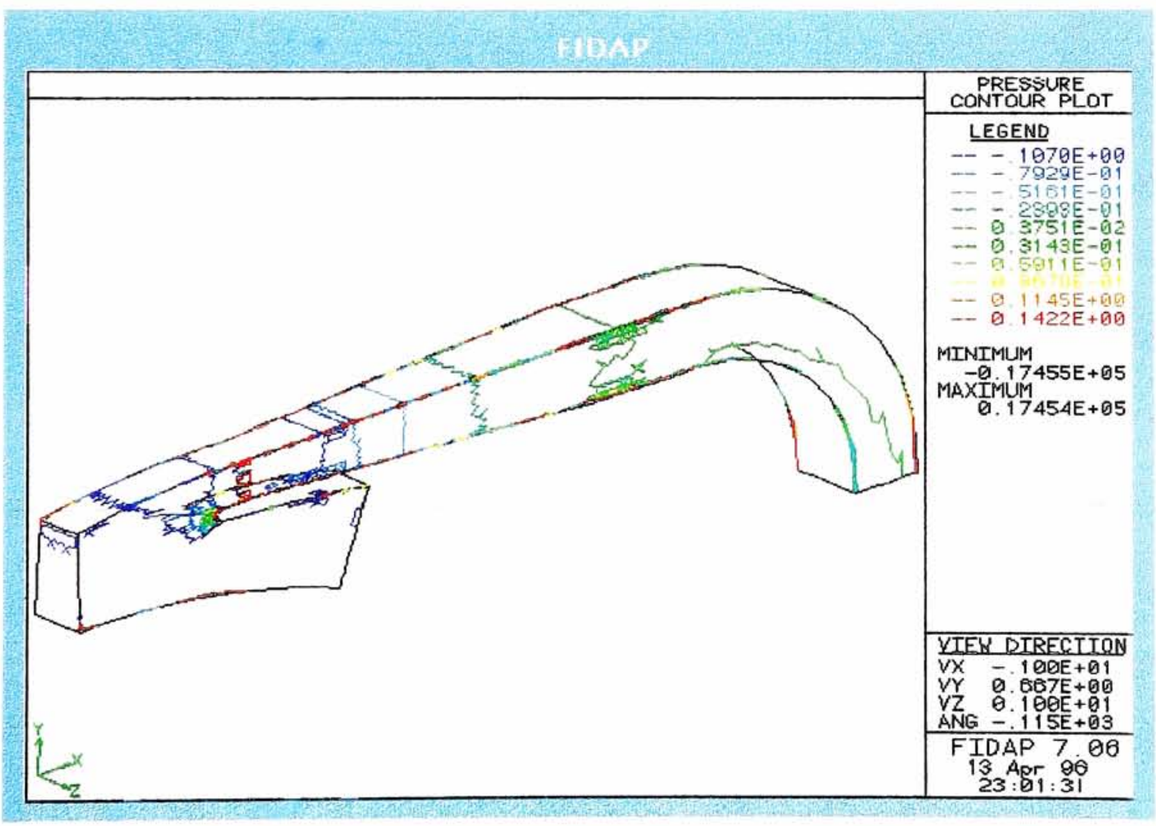


Figure 132 - Pressure Contour Plot (20% - 3%)

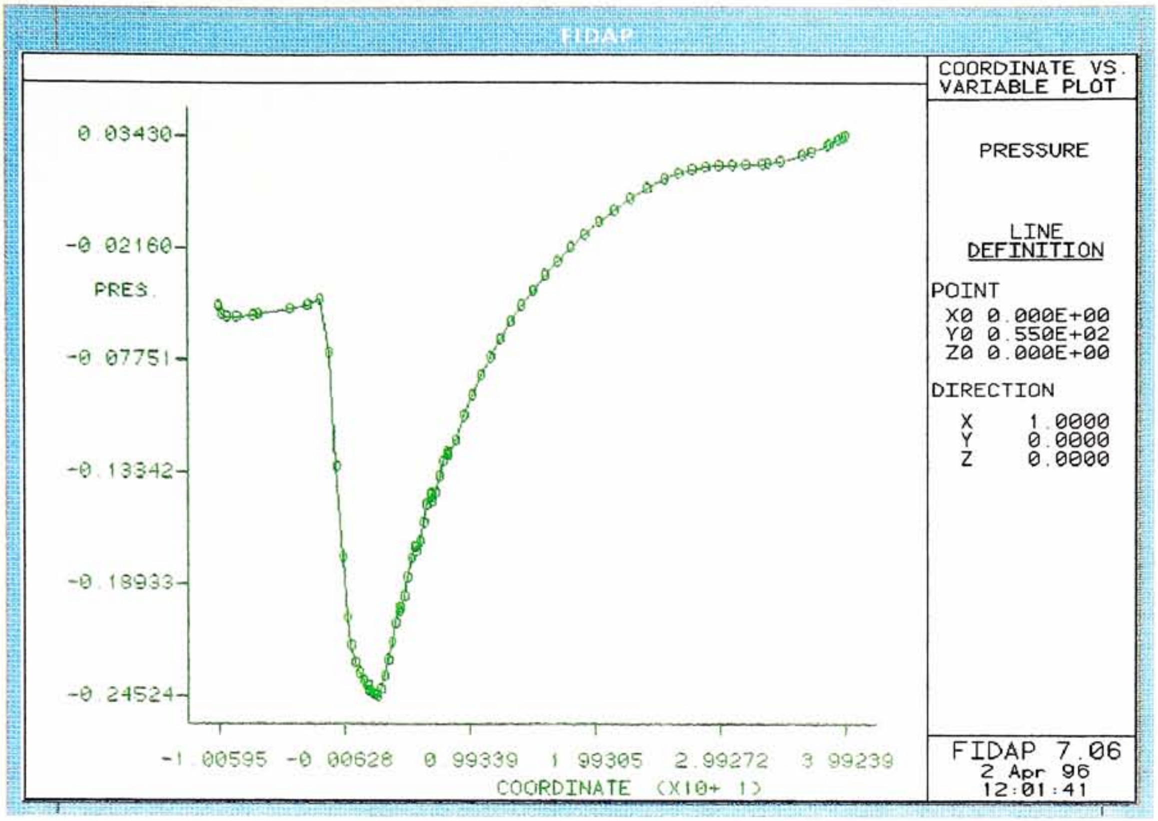


Figure 133 - Pressure Along the Centerline (20% - 3%)

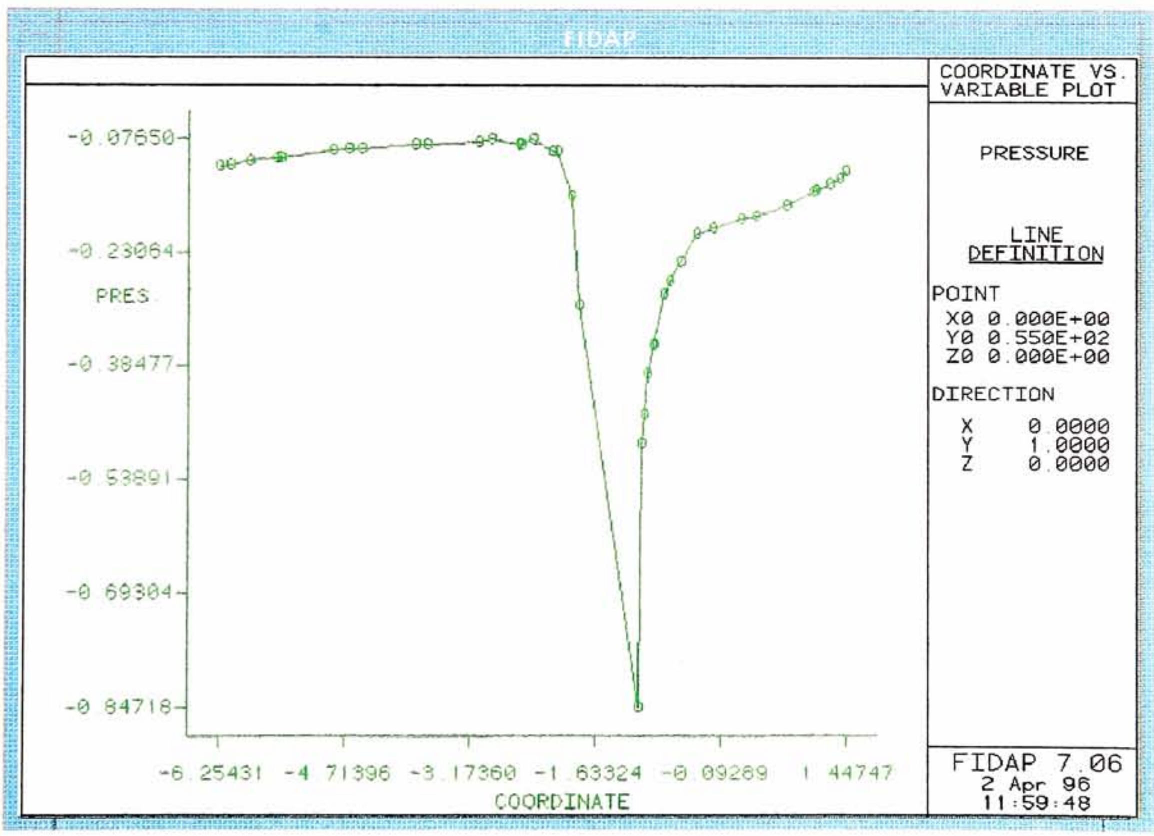


Figure 134 - Inlet Pressure (20% - 3%)

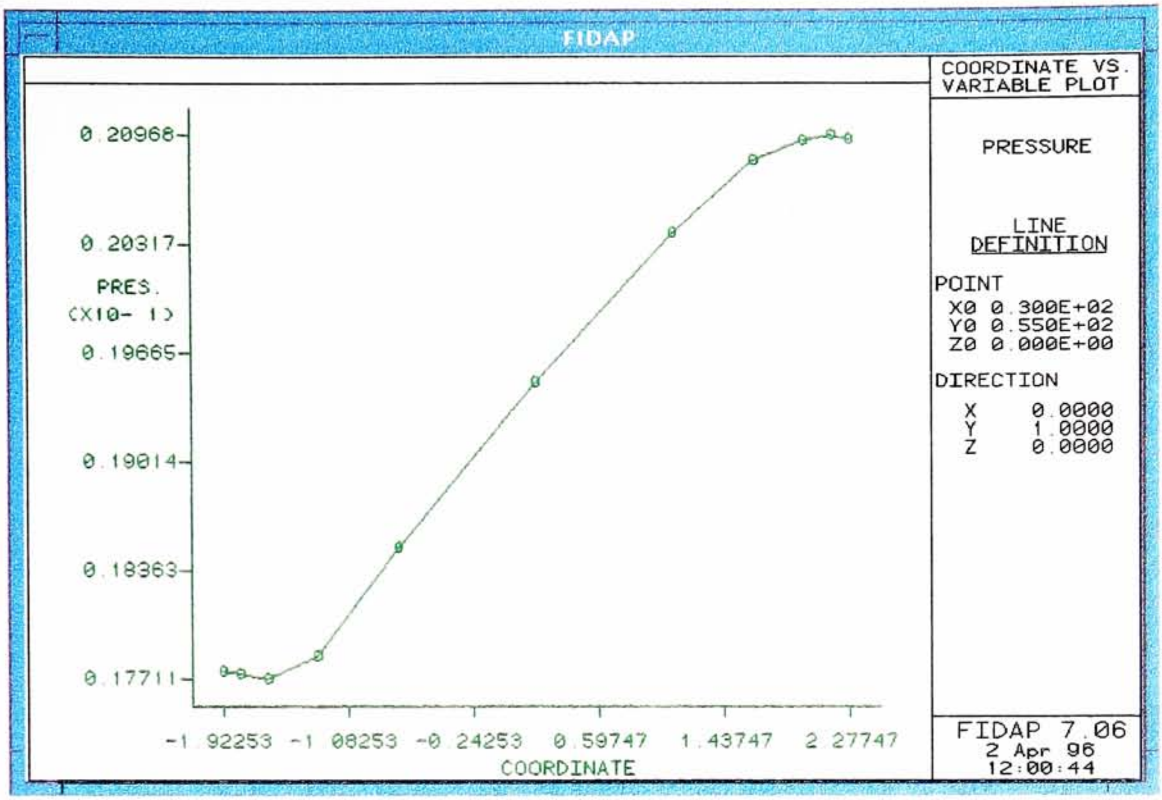


Figure 135 - Outlet Pressure (20% - 3%)

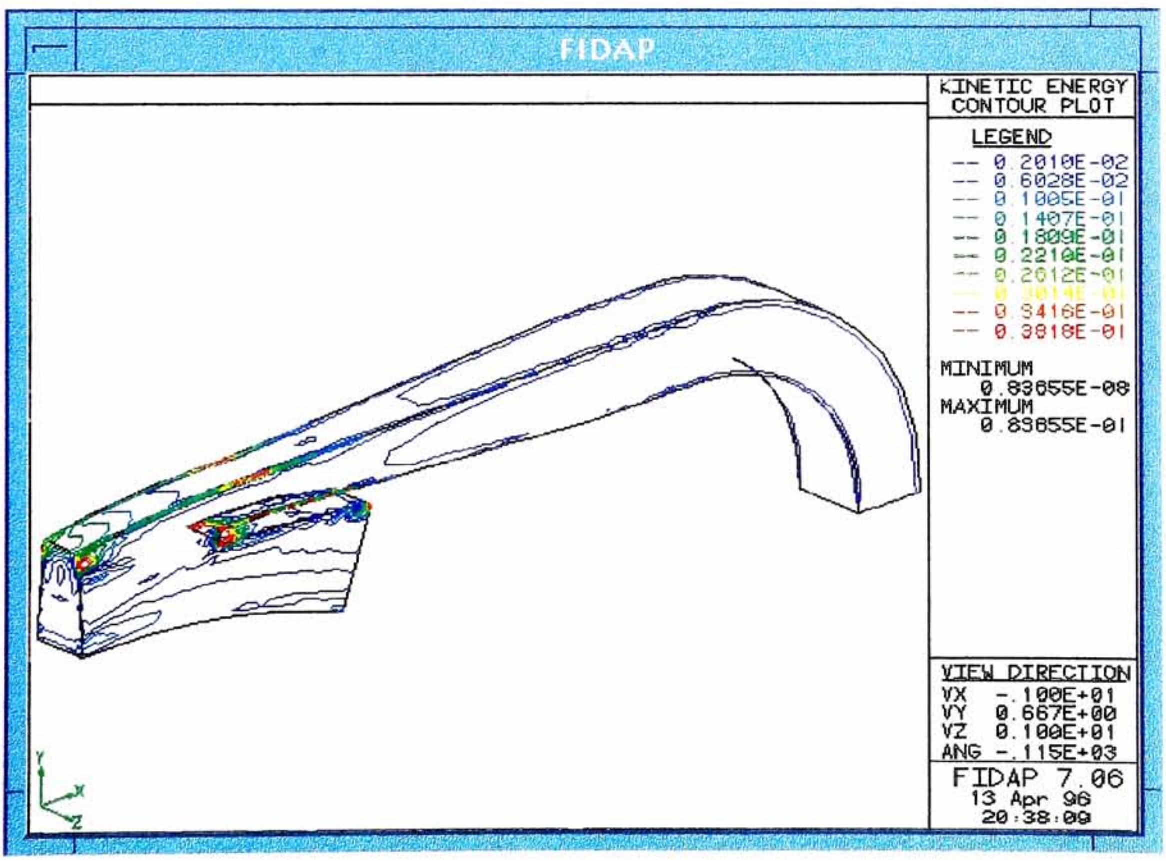


Figure 136 - Kinetic Energy Contour Plot (20% - 3%)

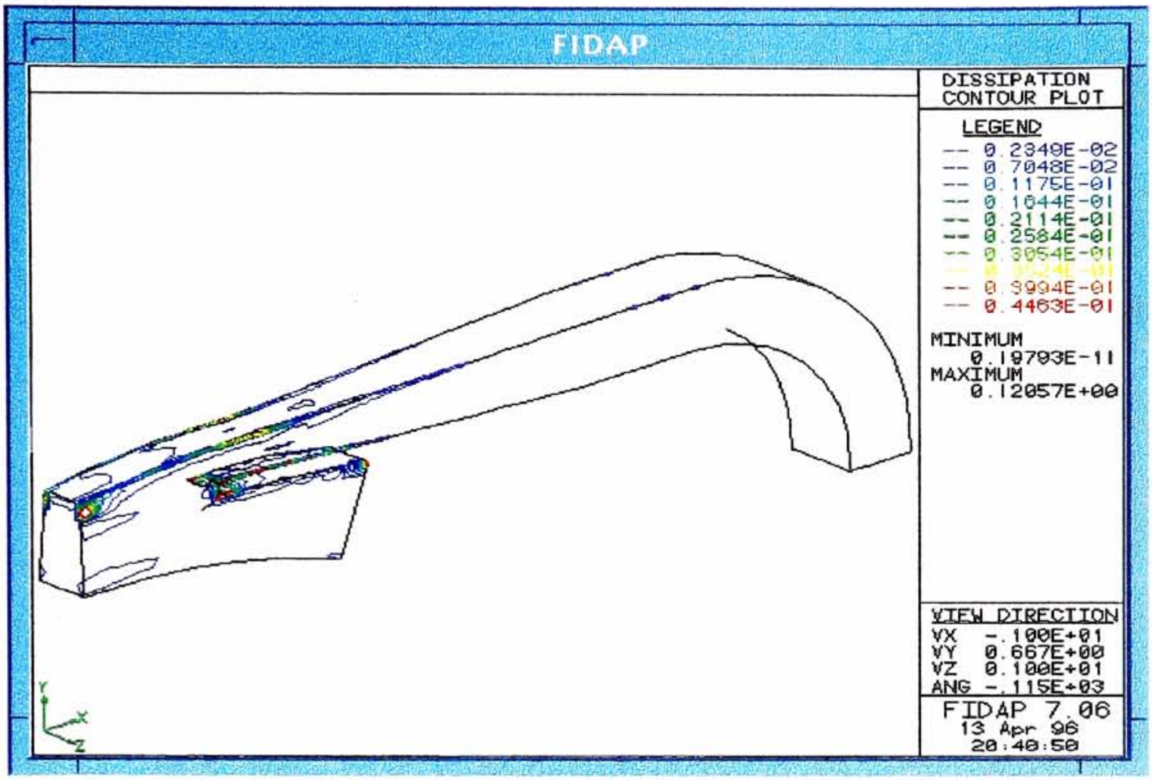


Figure 137 - Dissipation Contour Plot (20% - 3%)

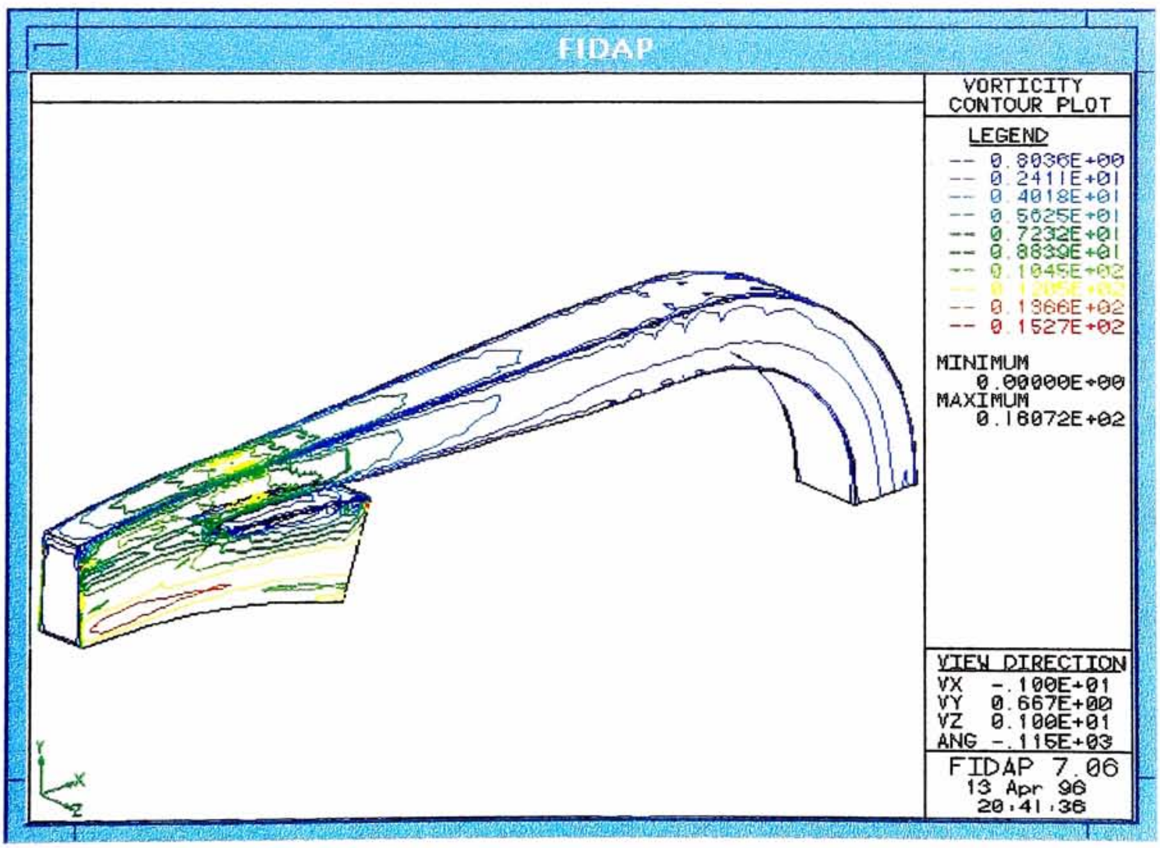


Figure 138 - Vorticity Contour Plot (20% - 3%)

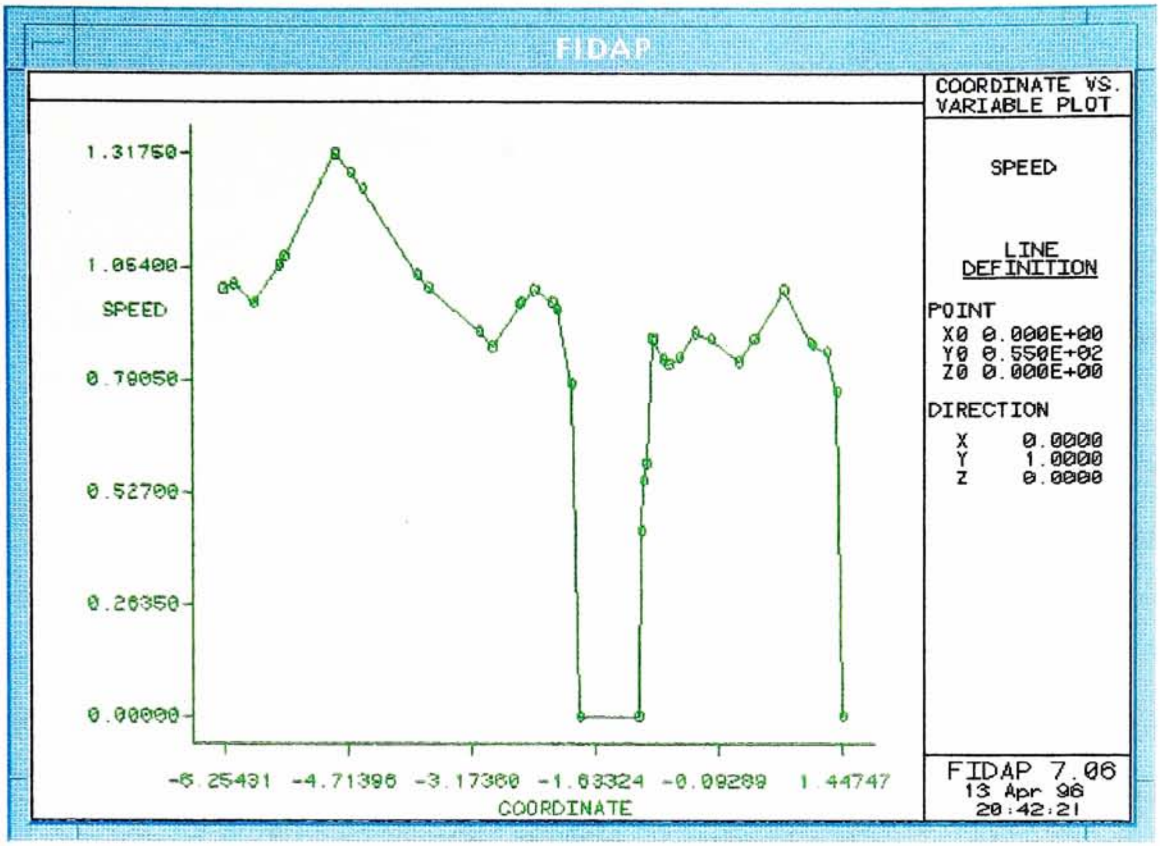


Figure 139 - Inlet Velocity Profile (20% - 3%)

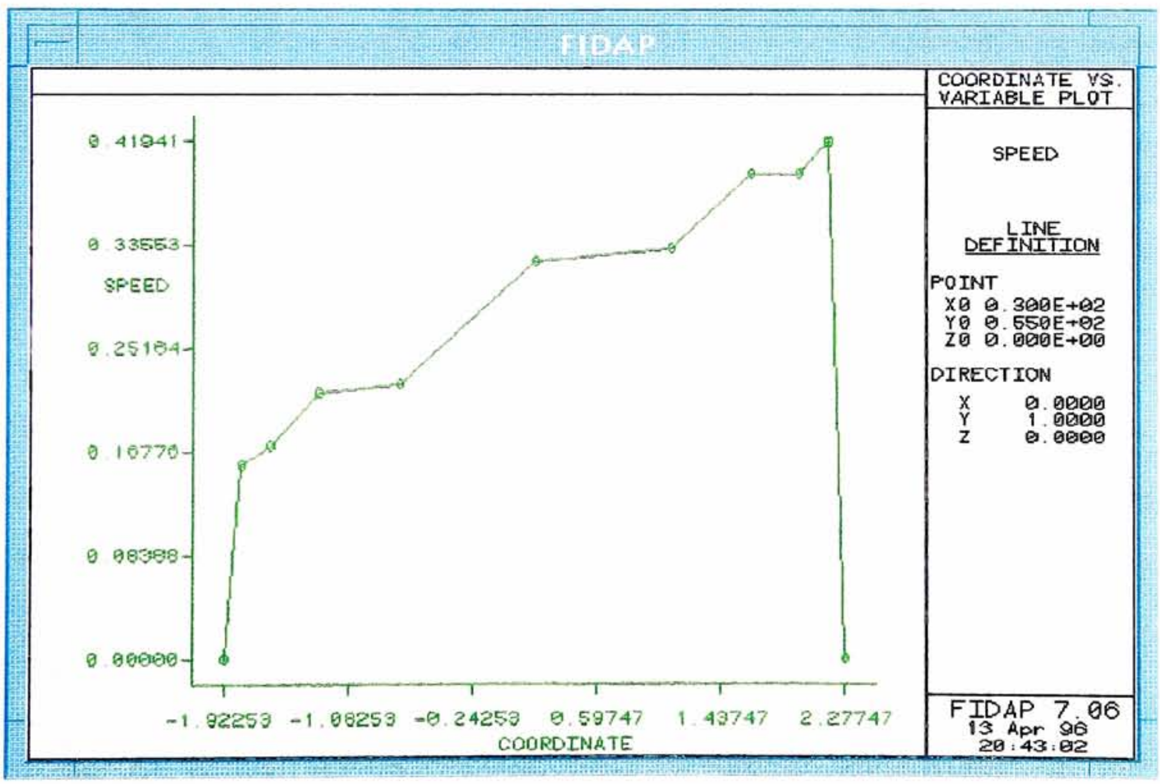


Figure 140 - Outlet Speed (20% - 3%)

7.4.5. 20% - 7% Flow Case.

The injection rate of 7% of the inlet mass flow rate through the six slits at an angle of 35 degrees, relative to the diffuser centerline, resulted in the application of a horizontal component of 0.01819 and a vertical component of 0.012738 as boundary conditions at the fluid injection slits (Refer to Appendix A for the calculations).

The velocity vector plot on the symmetry plane (Figure 141) shows that there is no separation. The same phenomenon can be seen in the shroud side plane (Figure 142) and on the bottom plane (Figure 143), which are the same planes used before to observe the area of maximum flow separation. The perpendicular views of the shroud side plane (Figure 144) and the bottom plane (Figure 147) also show no sign of flow separation. The effect of the injected fluid can be seen on the close ups of the shroud side. The first one (Figure 145) shows how the fluid is being injected into the diffuser and accelerates the particles that are starting to slow down near the wall. The second close up (Figure 146) shows the behavior of the fluid in the diffuser and once again it can be seen that there is no flow separation anywhere in the diffuser. The same behavior can be observed in the perpendicular view of the velocity vector on the bottom plane (Figure 147). A close up of this case was made to verify these results (Figure 148).

The pressure contour plot (Figure 150) and the pressure along the centerline (Figure 151) indicate a relatively uniform conversion of dynamic head to static pressure as the diffuser is traversed in the direction of flow. Using the pressure line plots from the bottom of the diffuser to the top, at the diffuser inlet (Figure 152) and outlet (Figure 153), the pressure recovery coefficient was calculated to be 0.639. From these results it can be seen how fluid injection improves the performance of the diffuser. For the 20% case, the pressure recovery coefficient , Cp, was calculated to be 0.50 and when 7% of the mass flow rate was injected, the pressure recovery coefficient came out to be 0.639.

The kinetic energy (Figure 154), dissipation (Figure 155), and vorticity (Figure 156) contour plots are included for flow verification. The majority of the kinetic energy is generated at the diffuser's entrance region on both the top and bottom planes near the shroud side wall, with a corresponding amount of dissipation in the same area. The vorticity, which is an indication of the level of viscosity present in the fluid at a particular location, shows also this behavior. This could be caused by the injection of fluid in this part of the diffuser. The velocity profiles that were graphed at positions near the diffuser inlet (Figure 157) and outlet (Figure 158) of the diffuser on the symmetry plane and are typical of turbulent flow in a diffuser. The inlet velocity profile shows the flow separation that occurs in the entrance to the vaneless section and the outlet velocity profile shows the significant reduction in the flow speed that is present in the diffuser's bottom plane near the shroud side.

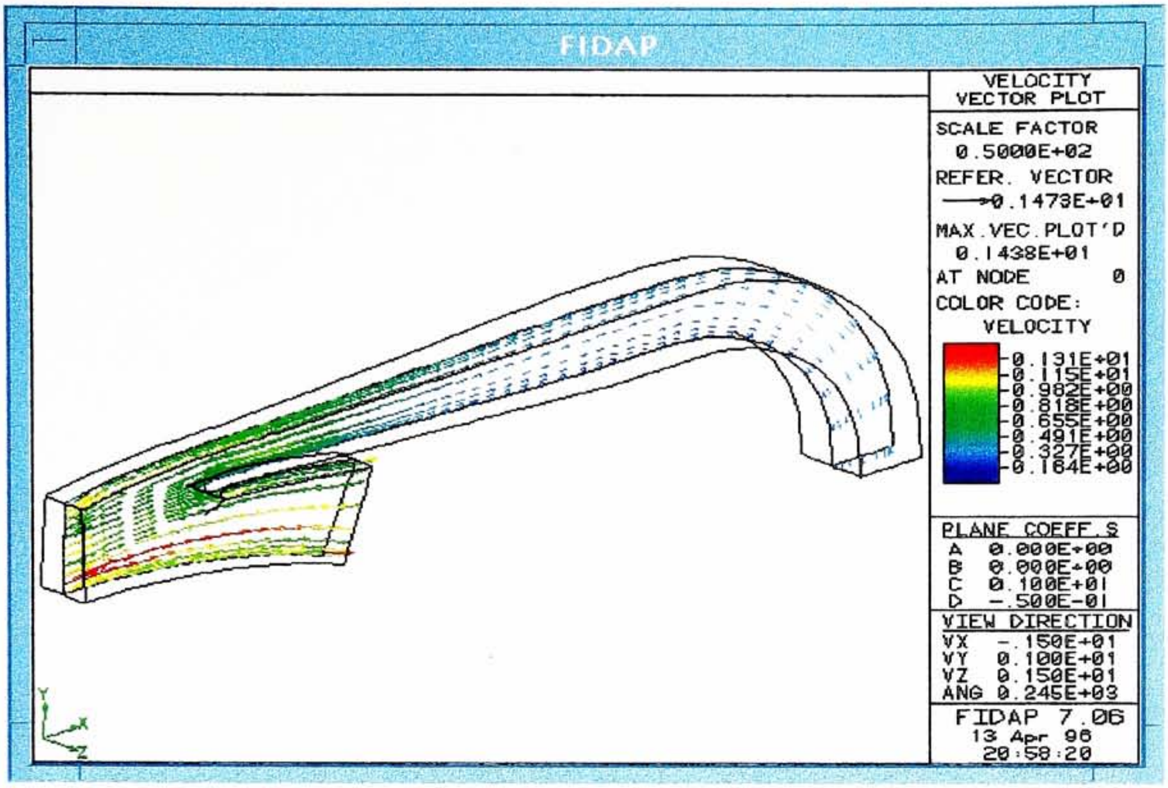


Figure 141 - Velocity on Symmetry Plane (20% - 7%)

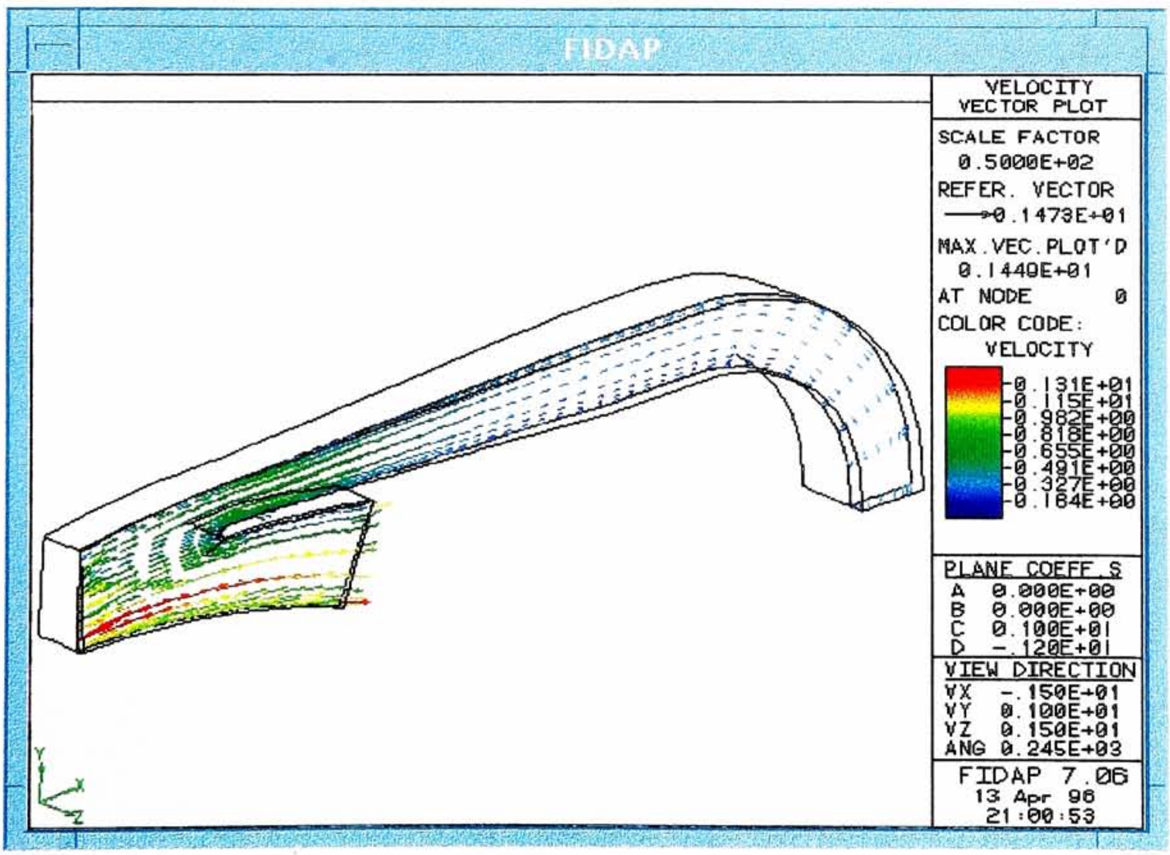


Figure 142 - Velocity on Shroud Side Plane (20% - 7%)

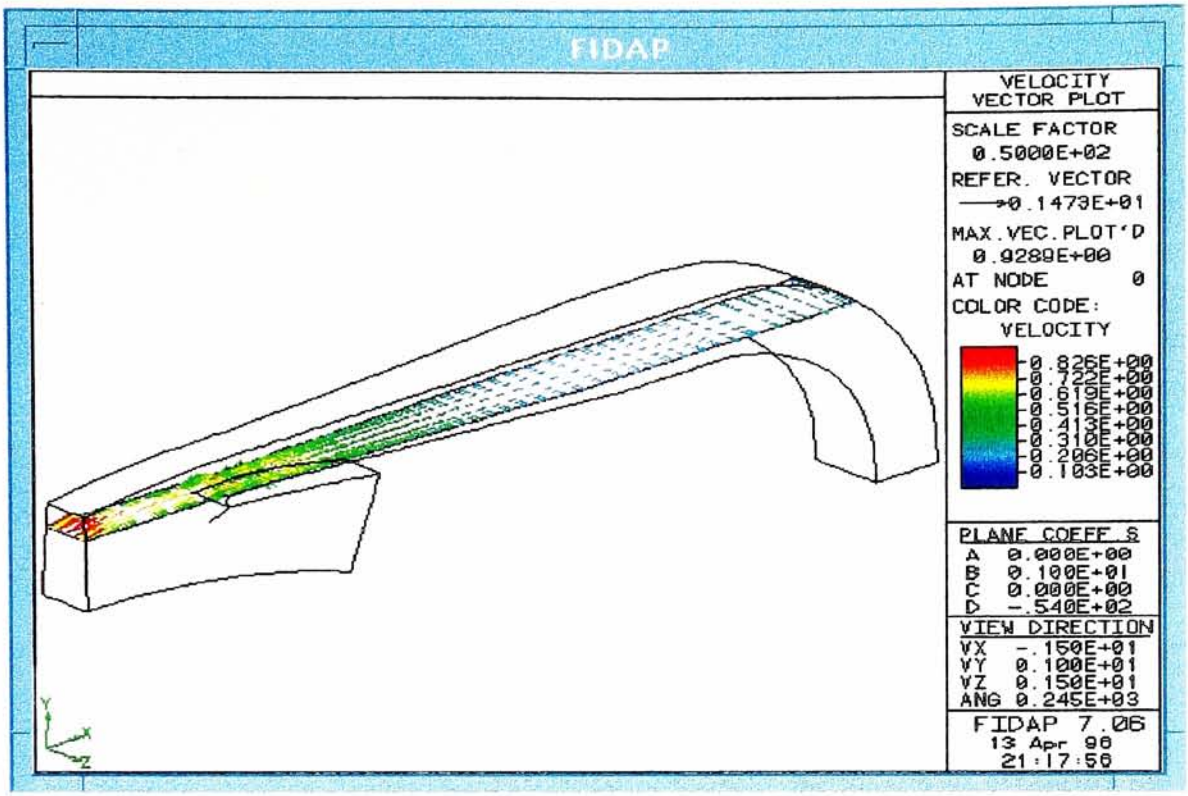


Figure 143 - Velocity on Bottom Plane (20% - 7%)

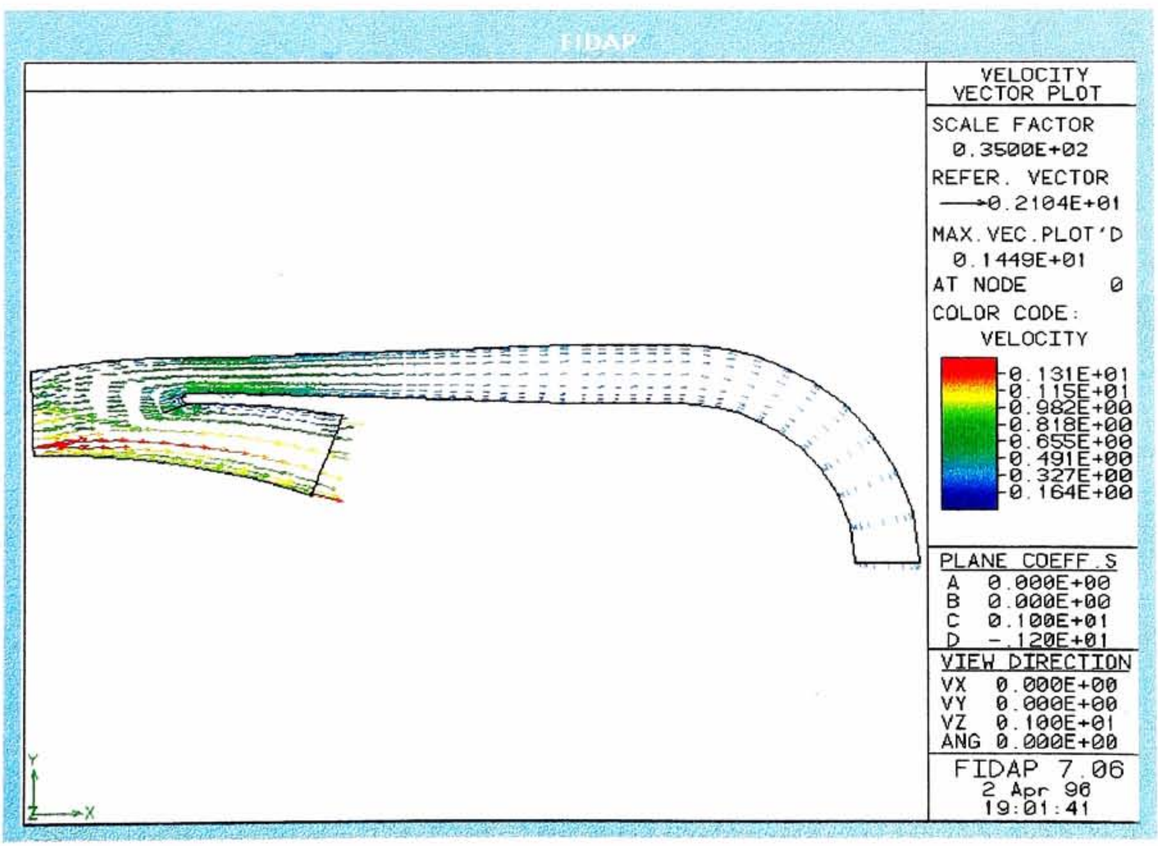


Figure 144 - 2-D View of velocity on Shroud Side (20% - 7%)

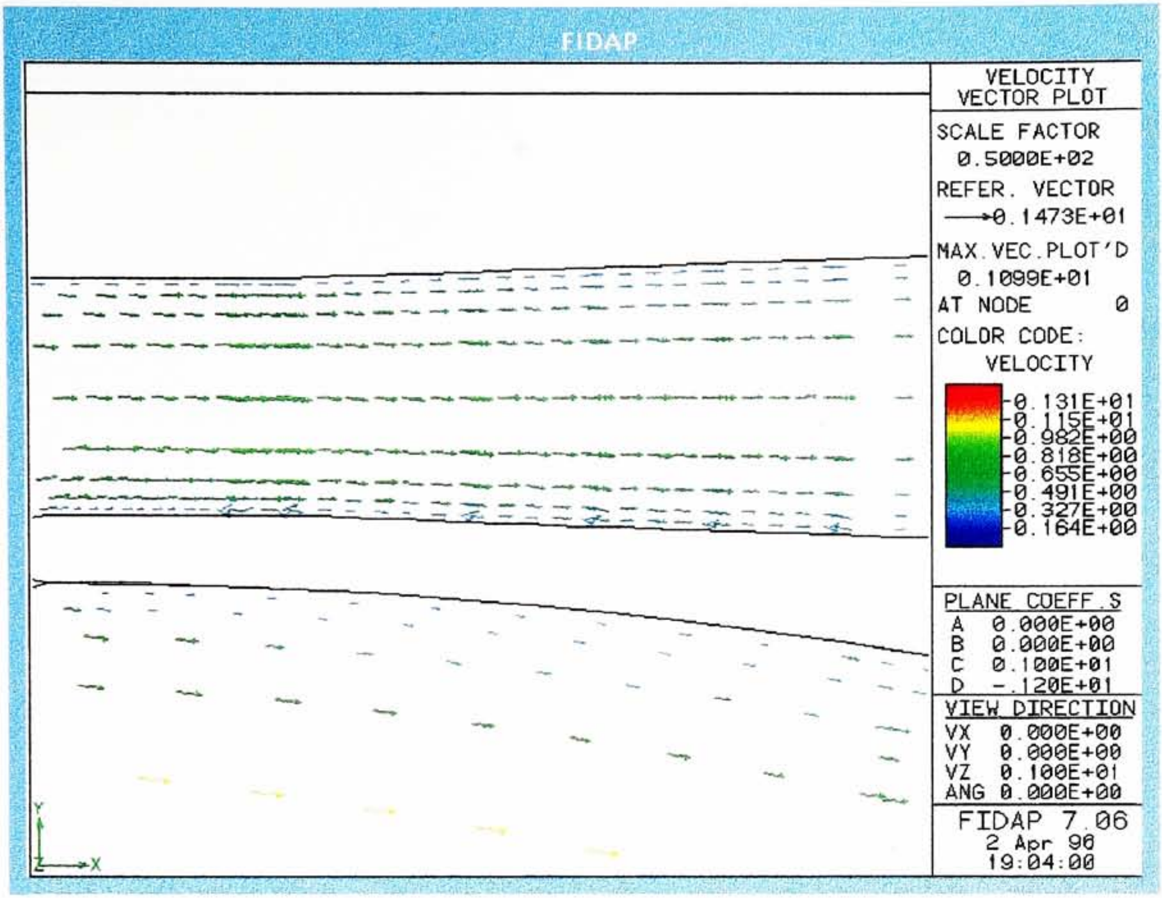


Figure 145 - Velocity at Diffuser's Throat on Shroud Side (20% - 7%)

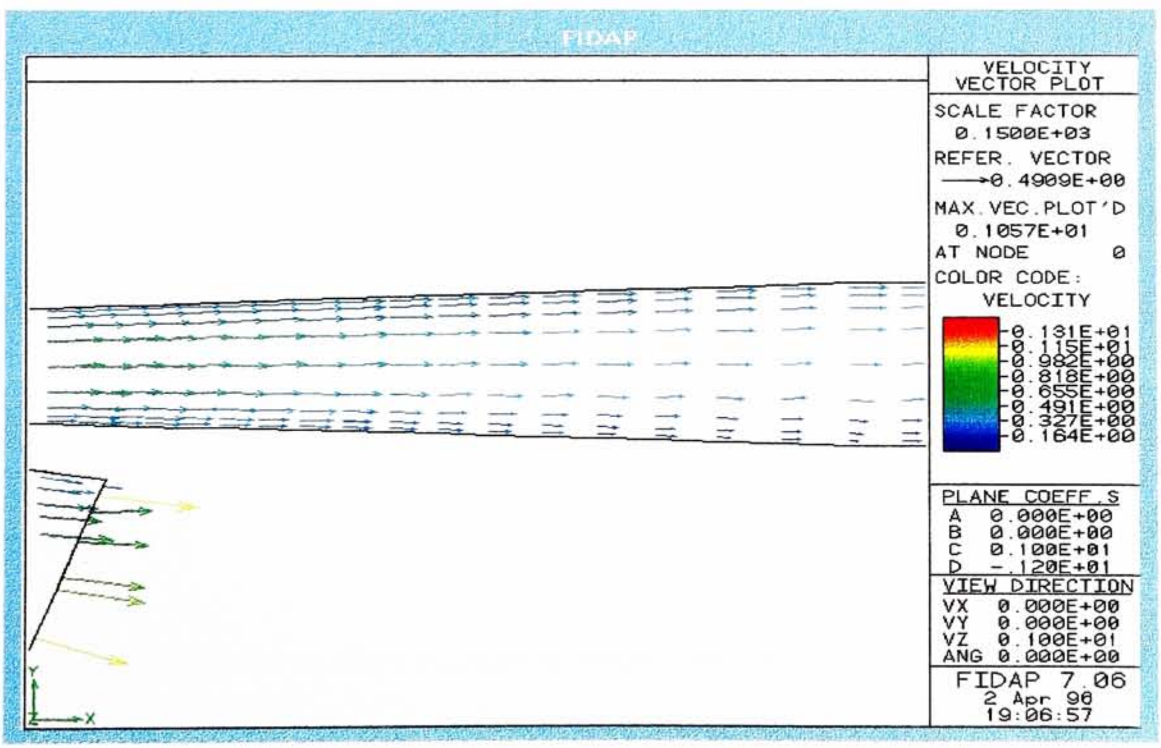


Figure 146 - Velocity at Outlet on Shroud Side (20% - 7%)

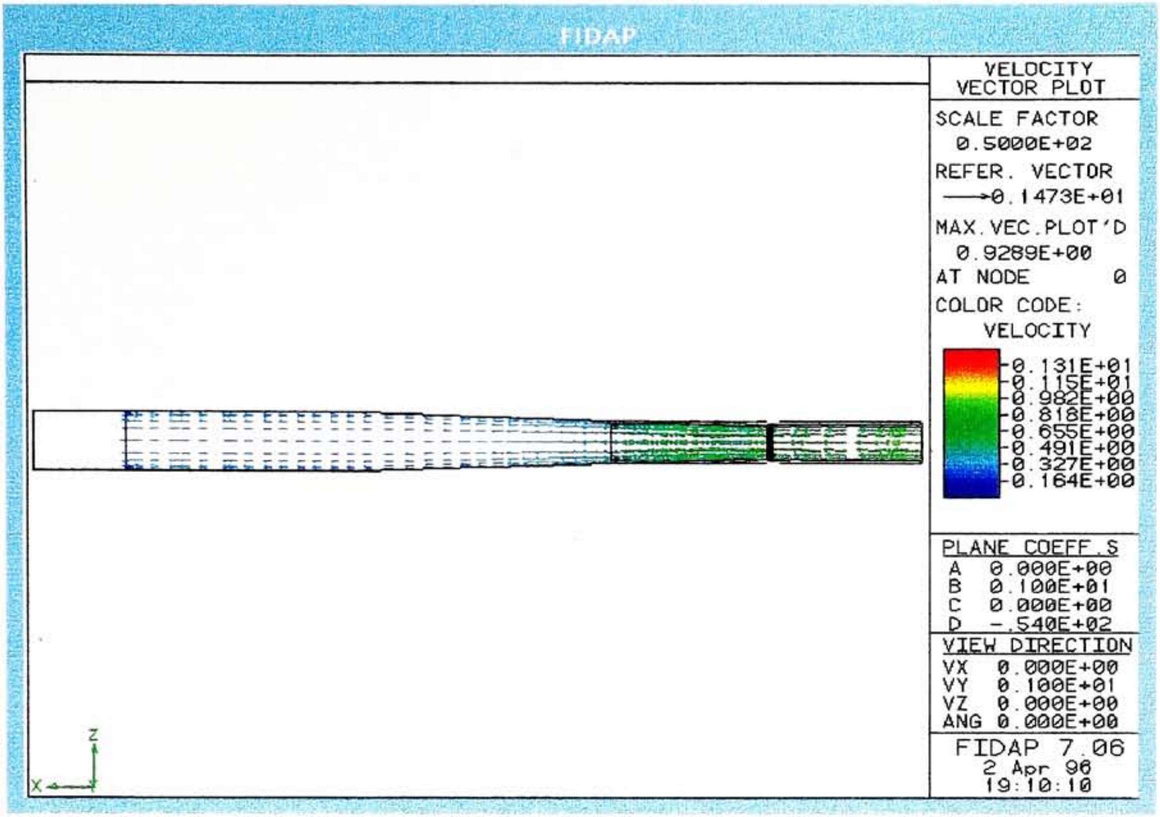


Figure 147 - 2-D View of Velocity on Bottom (20% - 7%)

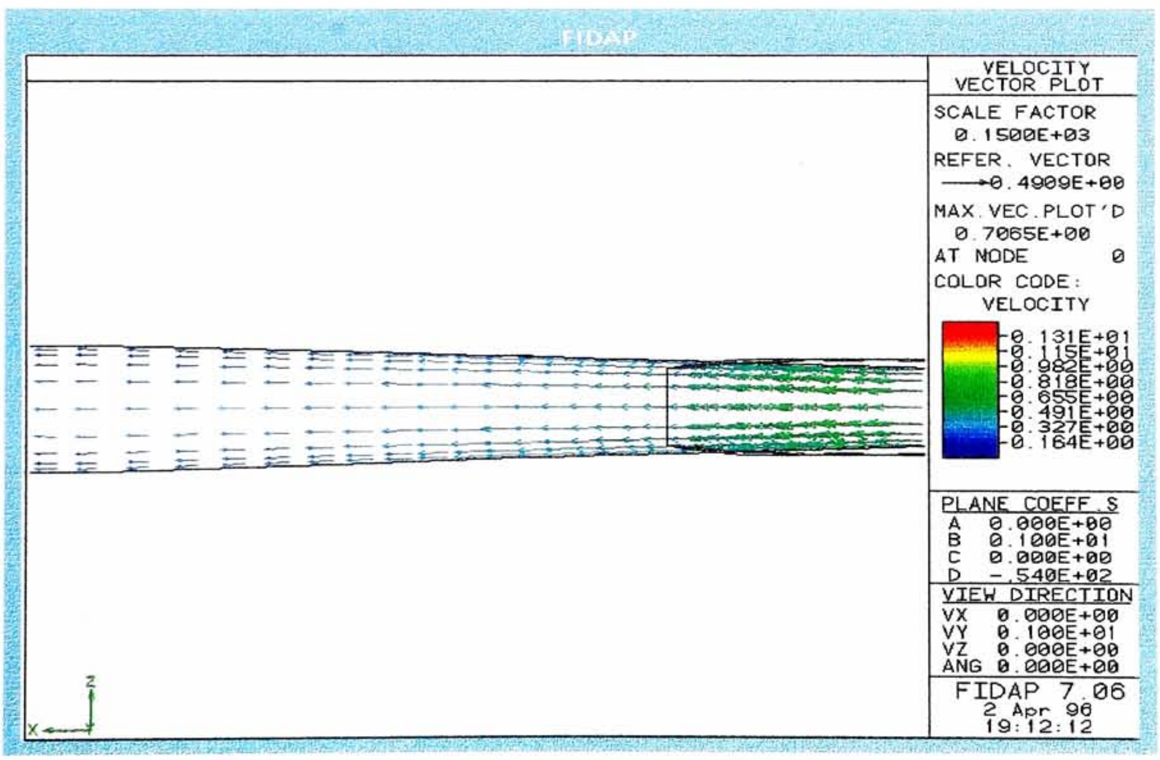


Figure 148 - Close Up of Velocity at Outlet on Bottom (20% - 7%)

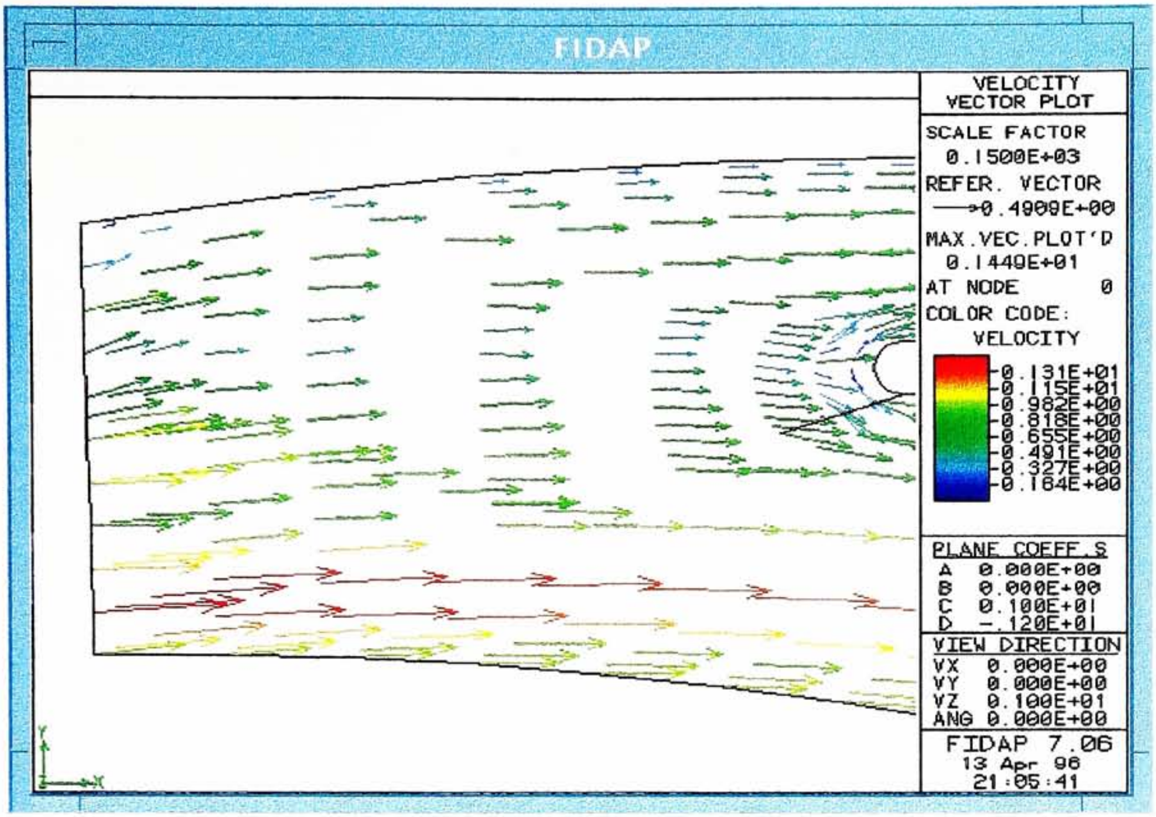


Figure 149 - Velocity at Inlet on Shroud Side (20% - 7%)

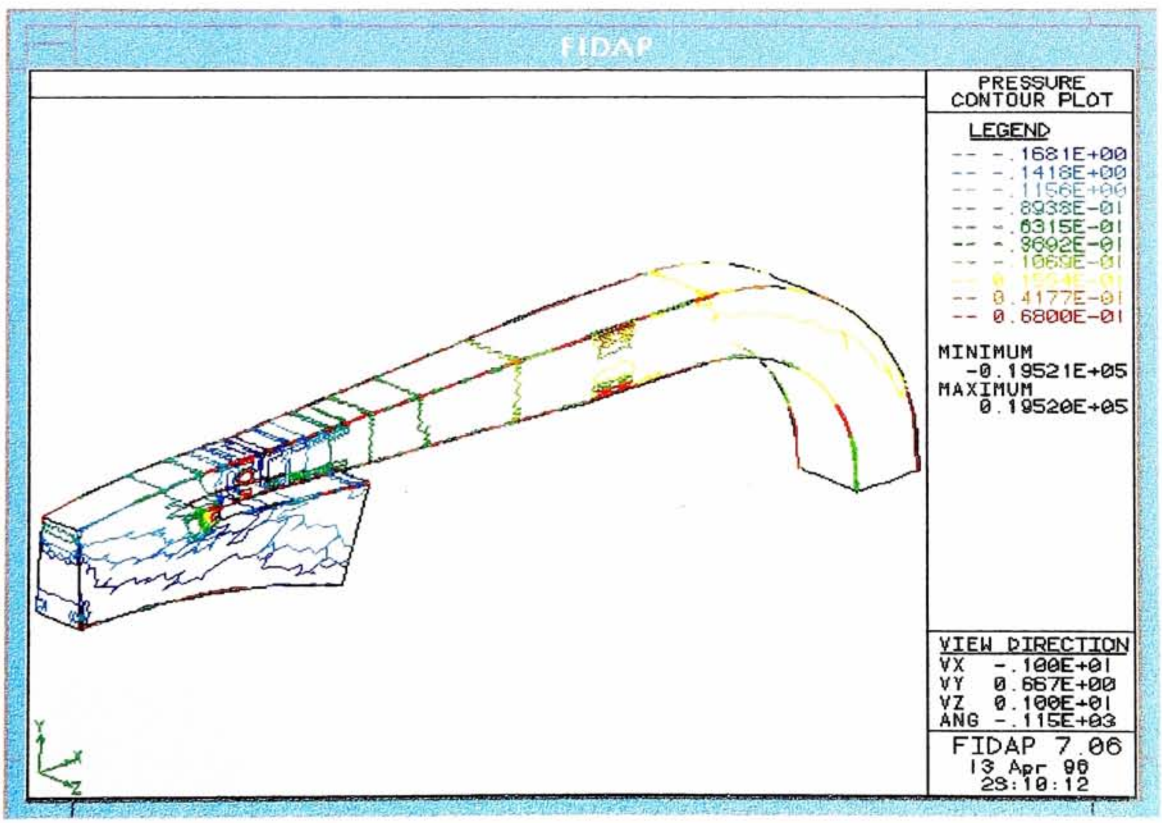


Figure 150 - Pressure Contour Plot (20% - 7%)

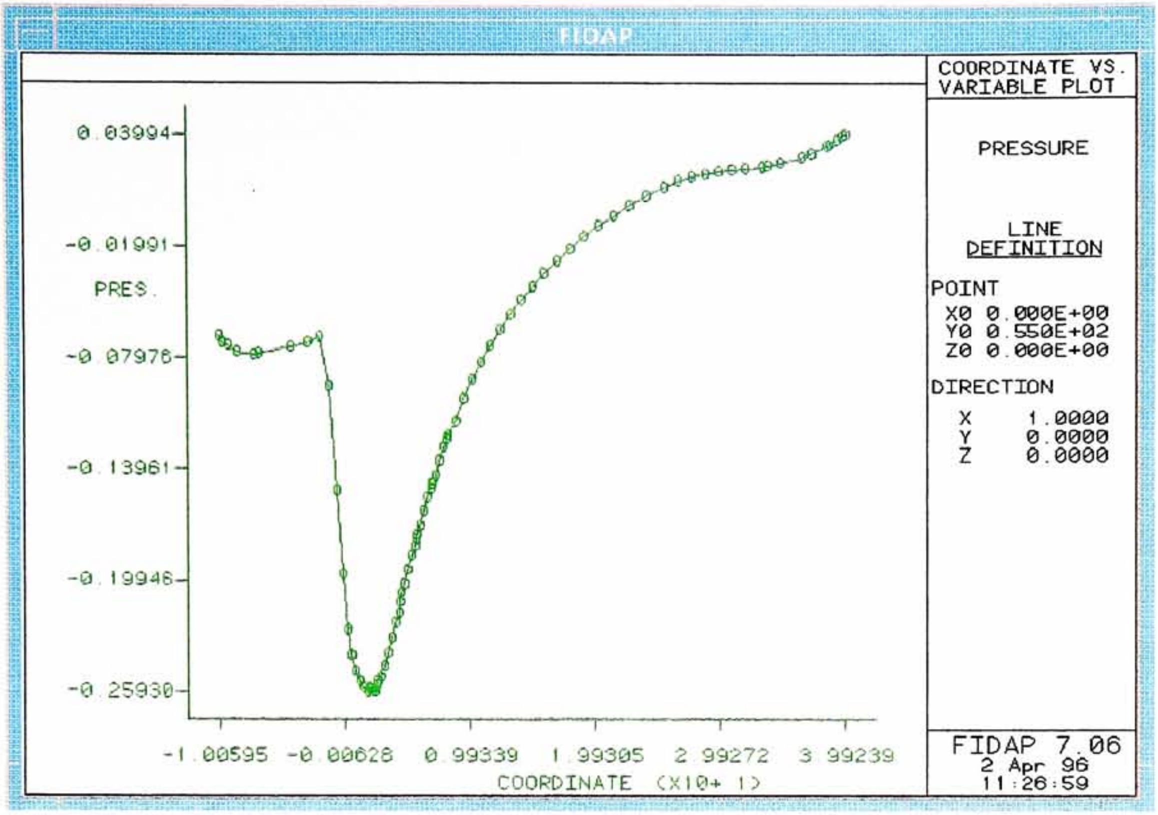


Figure 151 - Pressure Along the Centerline (20% - 7%)

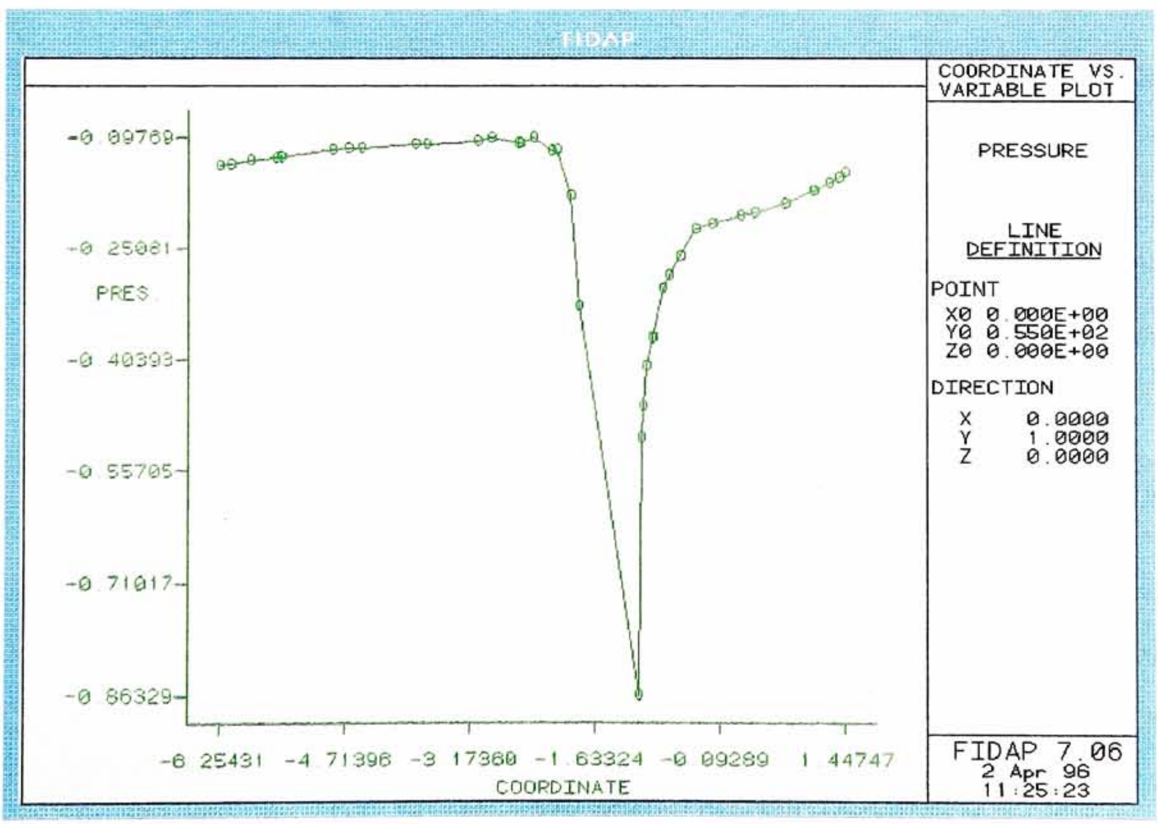


Figure 152 - Inlet Pressure (20% - 7%)

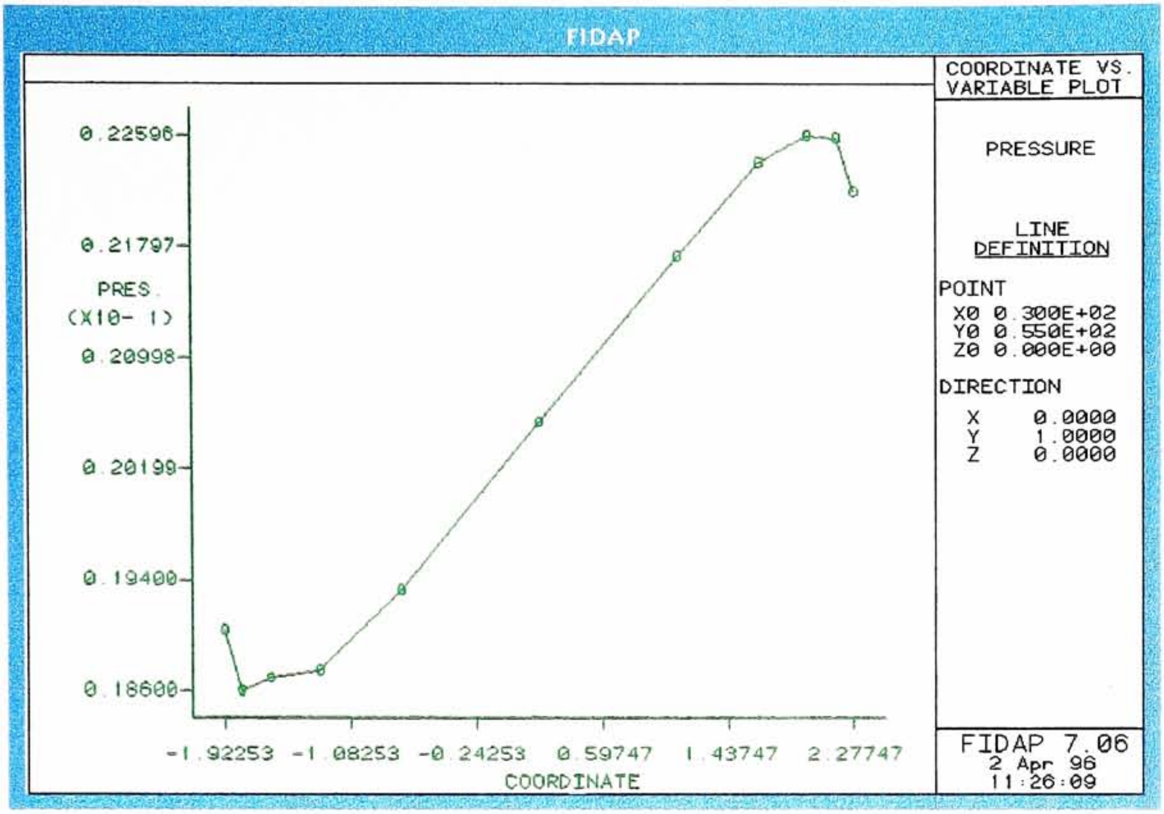


Figure 153 - Outlet Pressure (20% - 7%)

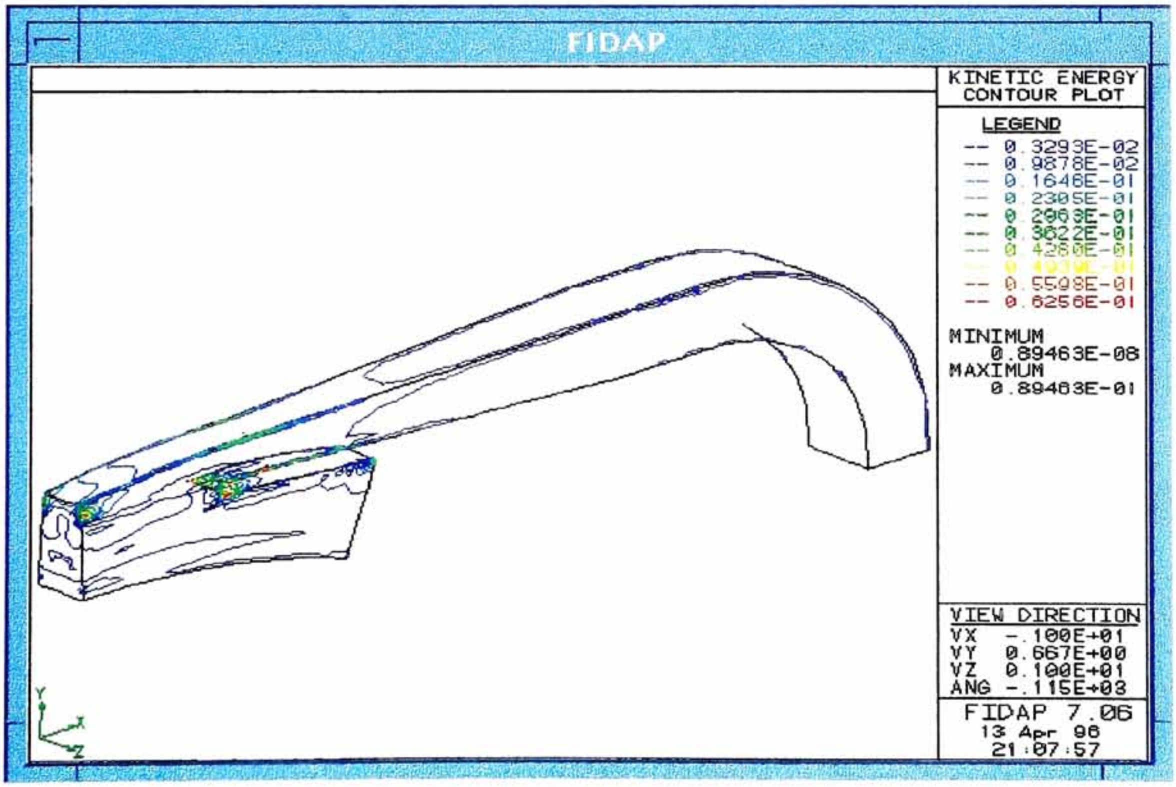


Figure 154 - Kinetic Energy Plot (20% - 7%)

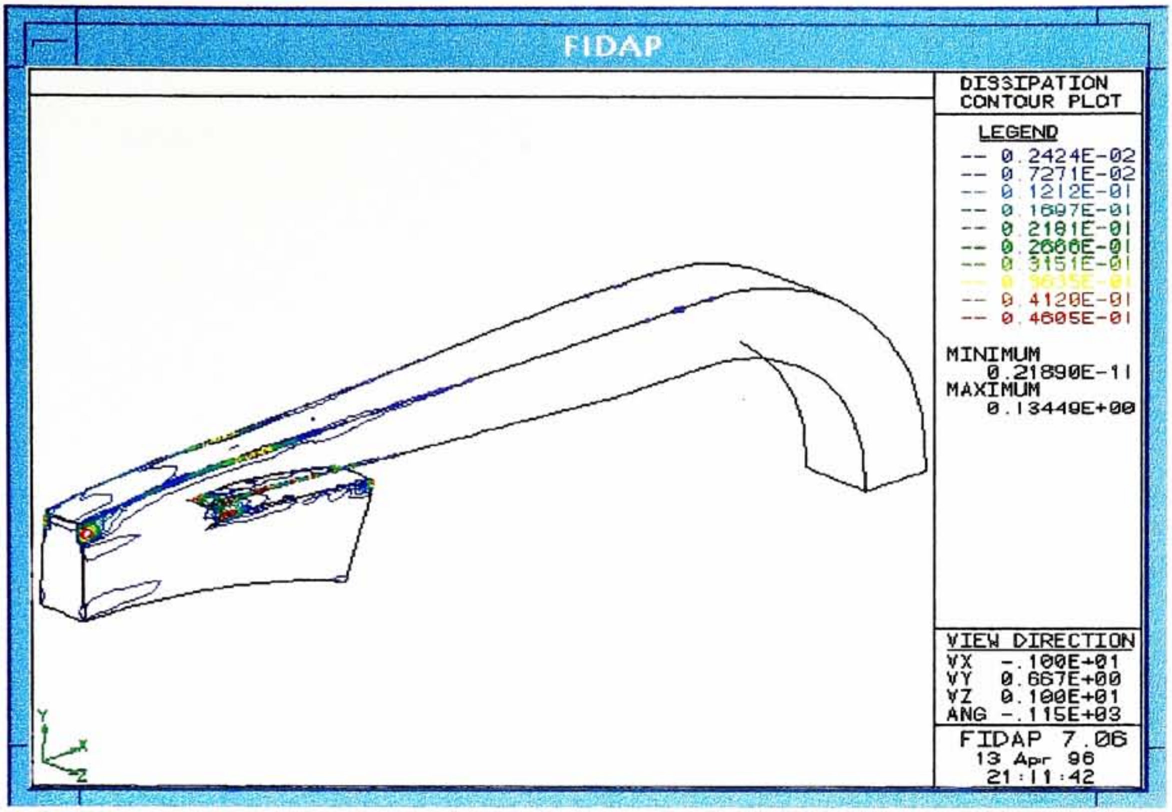


Figure 155 - Dissipation Contour Plot (20% - 7%)

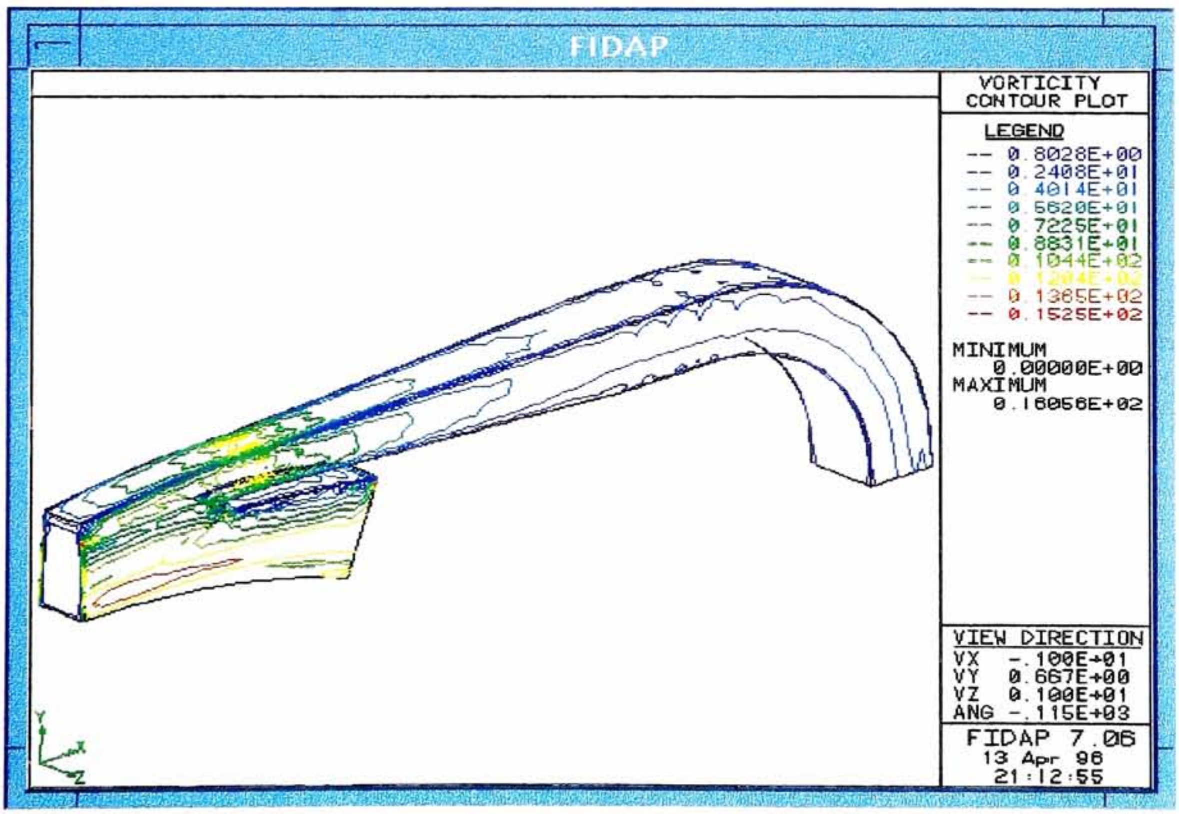


Figure 156 - Vorticity Contour Plot (20% - 7%)

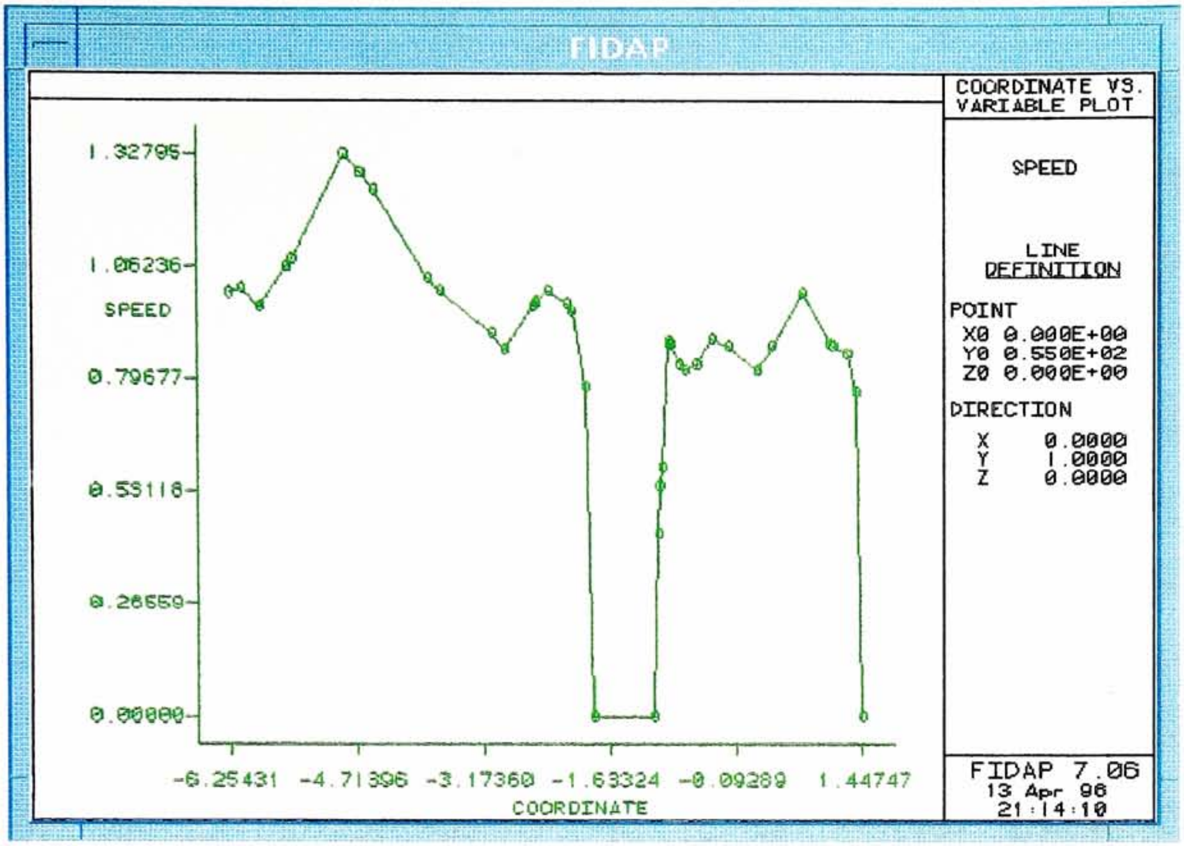


Figure 157 - Inlet Velocity Profile (20% - 7%)

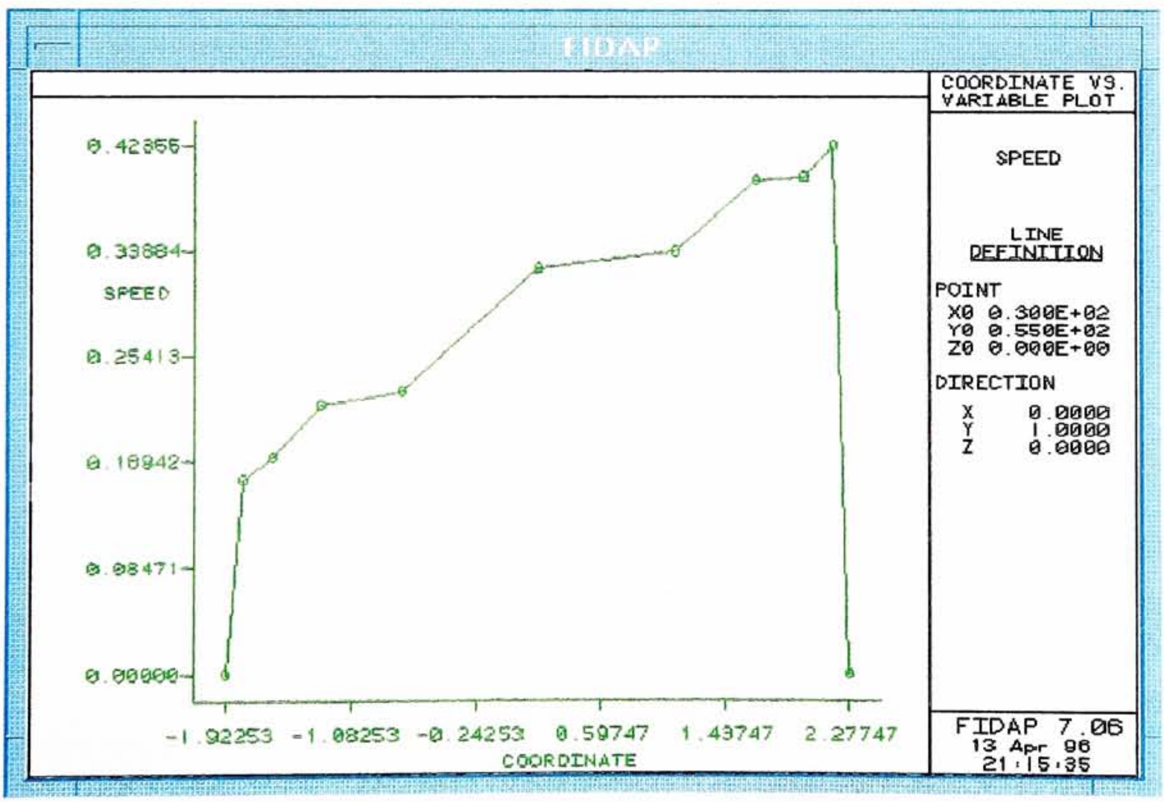


Figure 158 - Outlet Velocity Profile (20% - 7%)

7.4.6. 20% - 10% Flow Case.

The injection rate of 10% of the inlet mass flow rate through the six slits at an angle of 35 degrees, relative to the diffuser centerline, resulted in the application of a horizontal component of 0.0259 and a vertical component of 0.0182 as boundary conditions at the fluid injection slits (Refer to Appendix A for the calculations).

The velocity vector plot on the symmetry plane (Figure 159) shows that there is flow separation all along the bottom and top planes of the diffuser. The same phenomenon can be seen in the shroud side plane (Figure 160) and on the bottom plane (Figure 161), which are the same planes used before to observe the area of maximum flow separation. The perpendicular views of the shroud side plane (Figure 162) and the bottom plane (Figure 165) also show the effects of flow separation. The effect of the fluid injection can be seen on the close ups of the shroud side. The first one (Figure 163) shows how the large amount of fluid being injected into the diffuser disrupts the boundary layer in the bottom plane and increases the amount of separation in the diffuser. The second close up (Figure 164) shows the behavior of the fluid in the entire diffuser. It can be seen how the amount of separation increases as we go along the diffuser and also how the flow is beginning to separate in the top plane of the diffuser. This behavior was observed in the 60%-10% flow case but now it has been significantly increased. The conclusion that it is drawn out of this is that the separation in the bottom plane has an effect on the top plane, probably because of the effect of secondary flows. The same behavior can be observed in the perpendicular view of the velocity vector on the bottom plane (Figure 165). A close up of this case was made to verify these results (Figure 166).

As it was shown in previous cases, flow separation also was found in the diffuser's vaneless region in the shroud side (Figure 167). Secondary flow effects are probably the responsible for the creation of this area of flow separation. The pressure contour plot (Figure 168) the small amount of pressure recovery taking place in tl. diffuser. The pressure along the centerline (Figure 169) indicates a relatively uniform conversion of dynamic head to static pressure as the diffuser is traversed in the direction of flow. Using the pressure line plots, from the bottom of the diffuser to the top, at the diffuser inlet (Figure 170) and outlet (Figure 171), the pressure recovery coefficient was calculated to be 0.4214. This result indicates that the optimum amount of fluid to be injected in the diffuser for this case should be around 7% of the mass flow rate.

The kinetic energy (Figure 172), dissipation (Figure 173), and vorticity (Figure 174) contour plots are included for flow verification. The majority of the kinetic energy is generated at the diffuser's entrance region on both the top and bottom planes near the shroud side wall, with a corresponding amount of dissipation in the same area. The vorticity, which is an indication of the level of viscosity present in the fluid at a particular location, shows also this behavior. This could be caused by the injection of fluid in this part of the diffuser. The velocity profiles that were graphed at positions near the diffuser inlet (Figure 175) and outlet (Figure 176) of the diffuser on the symmetry plane and are typical of turbulent flow in a diffuser. The inlet velocity profile shows the flow separation that occurs in the entrance to the vaneless section and the outlet velocity profile shows the significant reduction in the flow speed that is present in the diffuser's bottom plane near the shroud side.

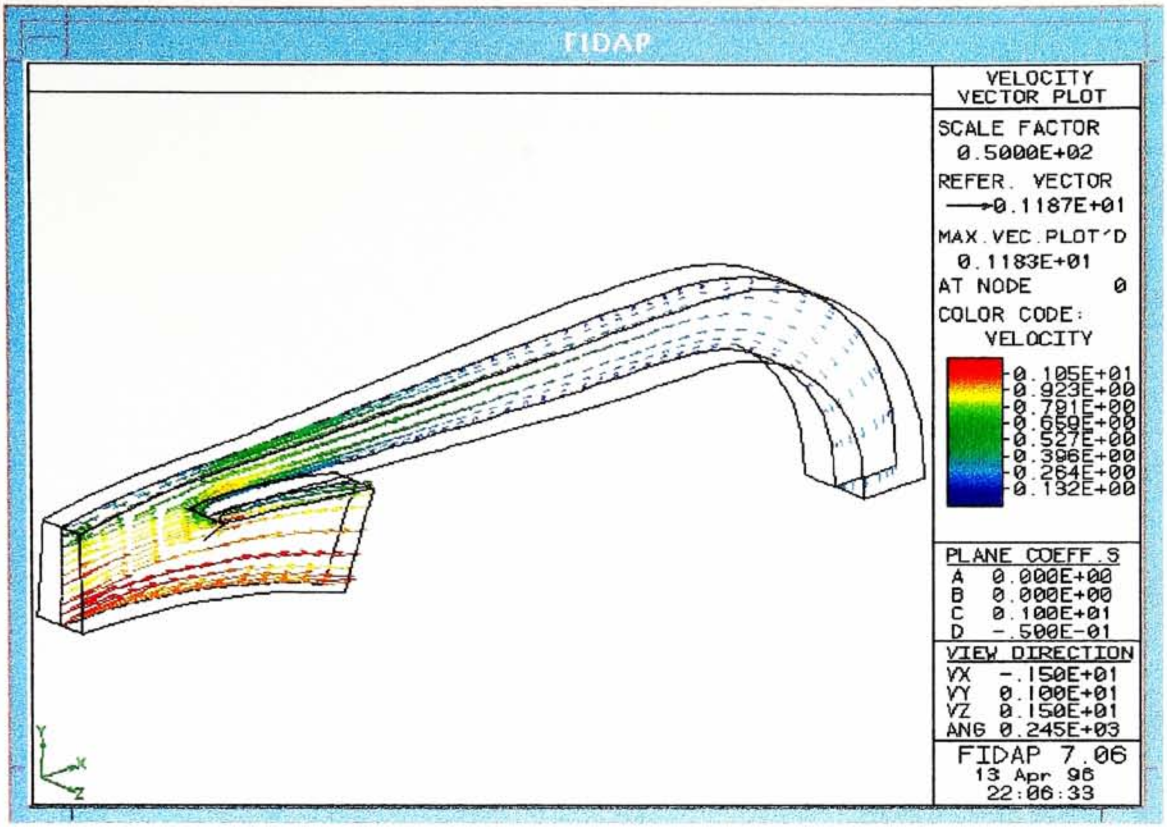


Figure 159 - Velocity on Symmetry Plane (20% - 10%)

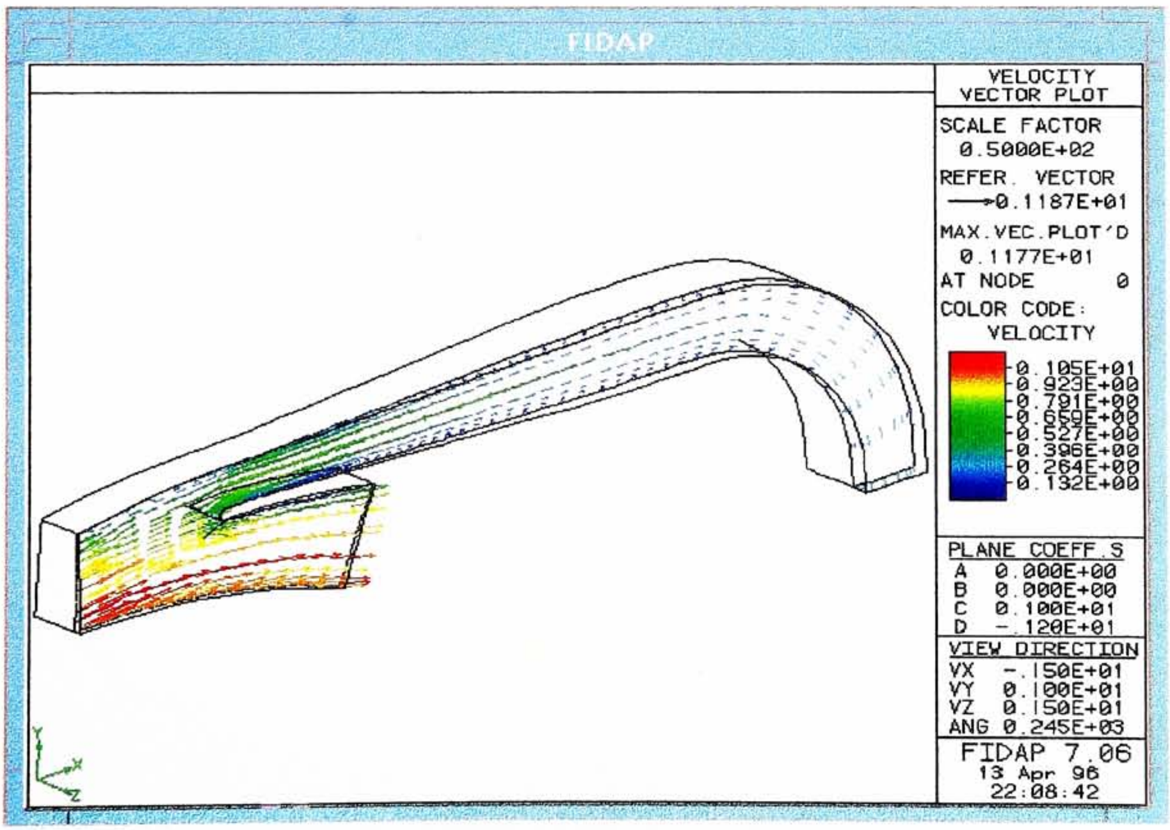


Figure 160 - Velocity on Shroud Side Plane (20% -10%)

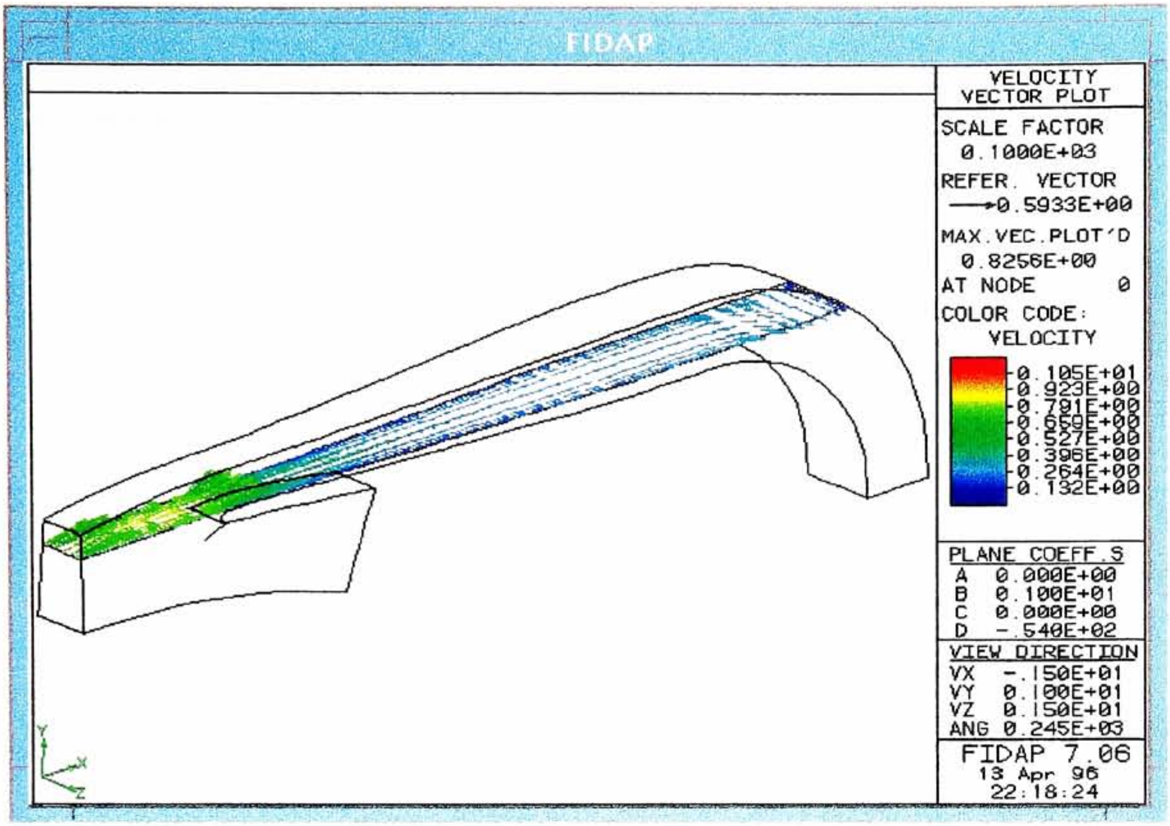


Figure 161 - Velocity on Bottom Plane (20% -10%)

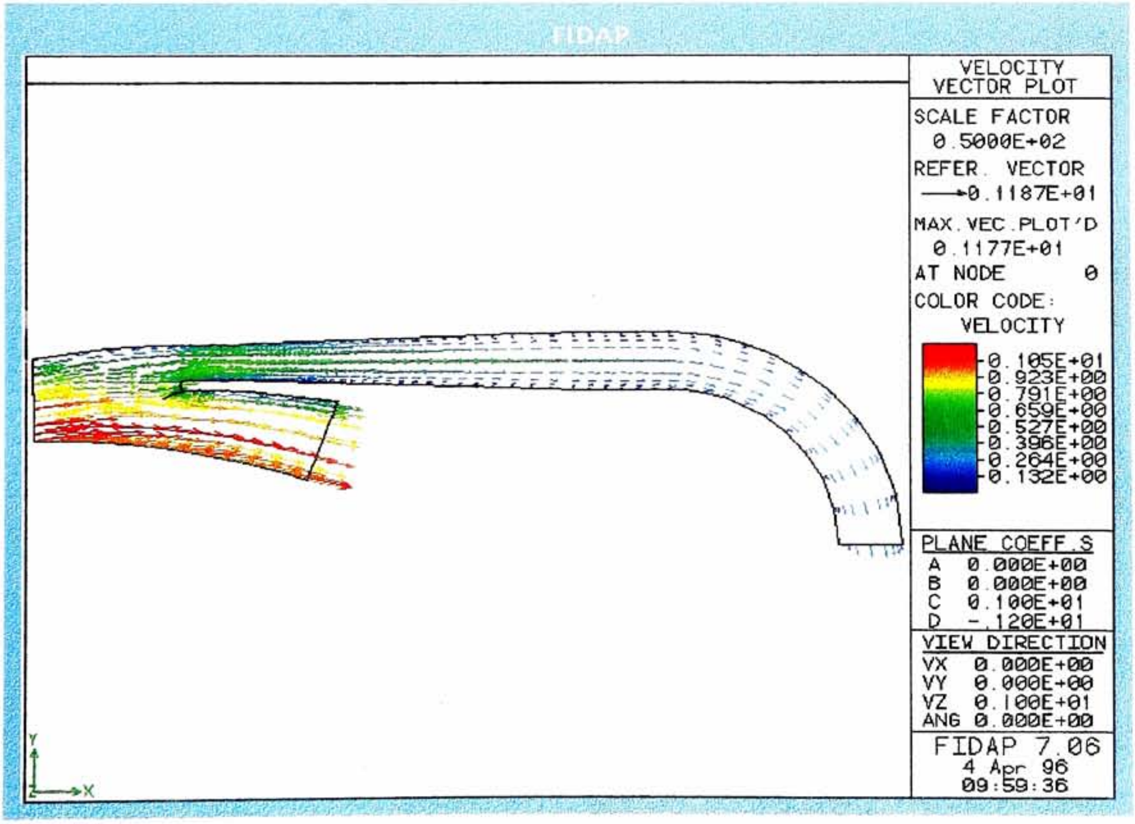


Figure 162 - 2-D View of Velocity on Shroud Side (20% -10%)

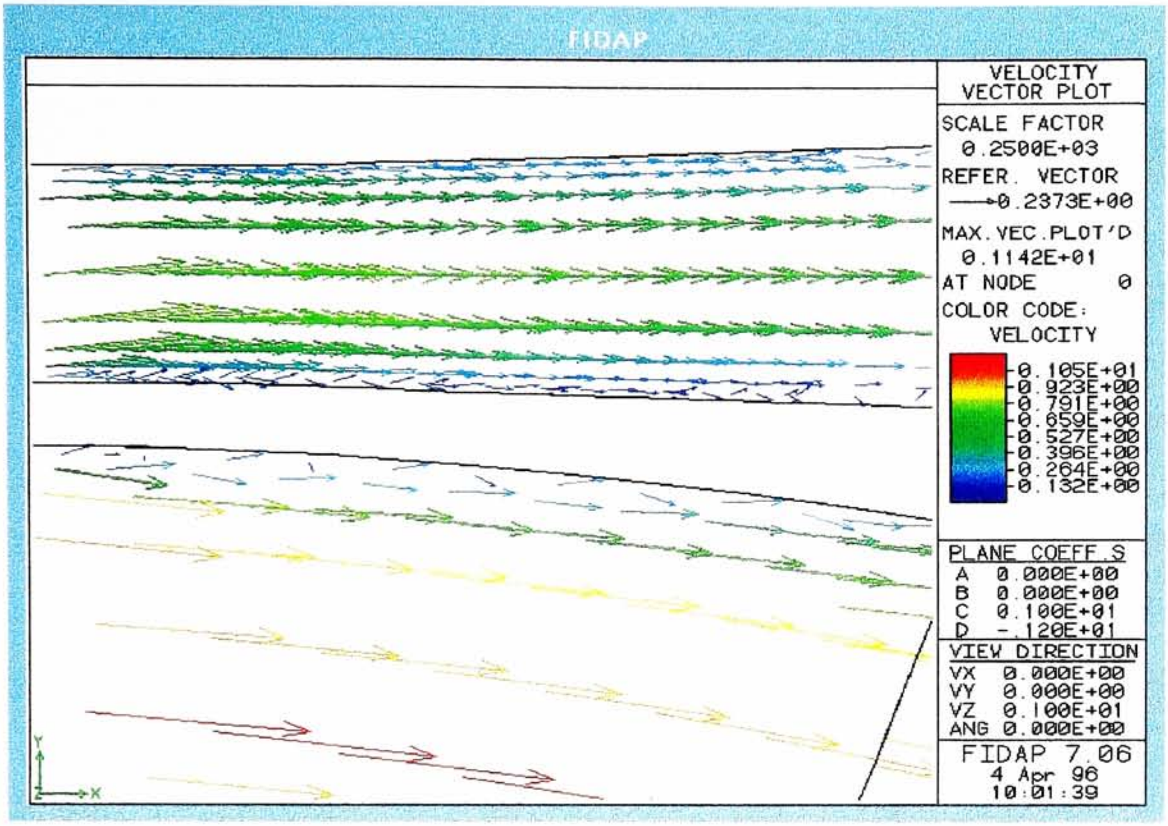


Figure 163 - Velocity at Diffuser's Throat on Shroud Side (20% - 10%)

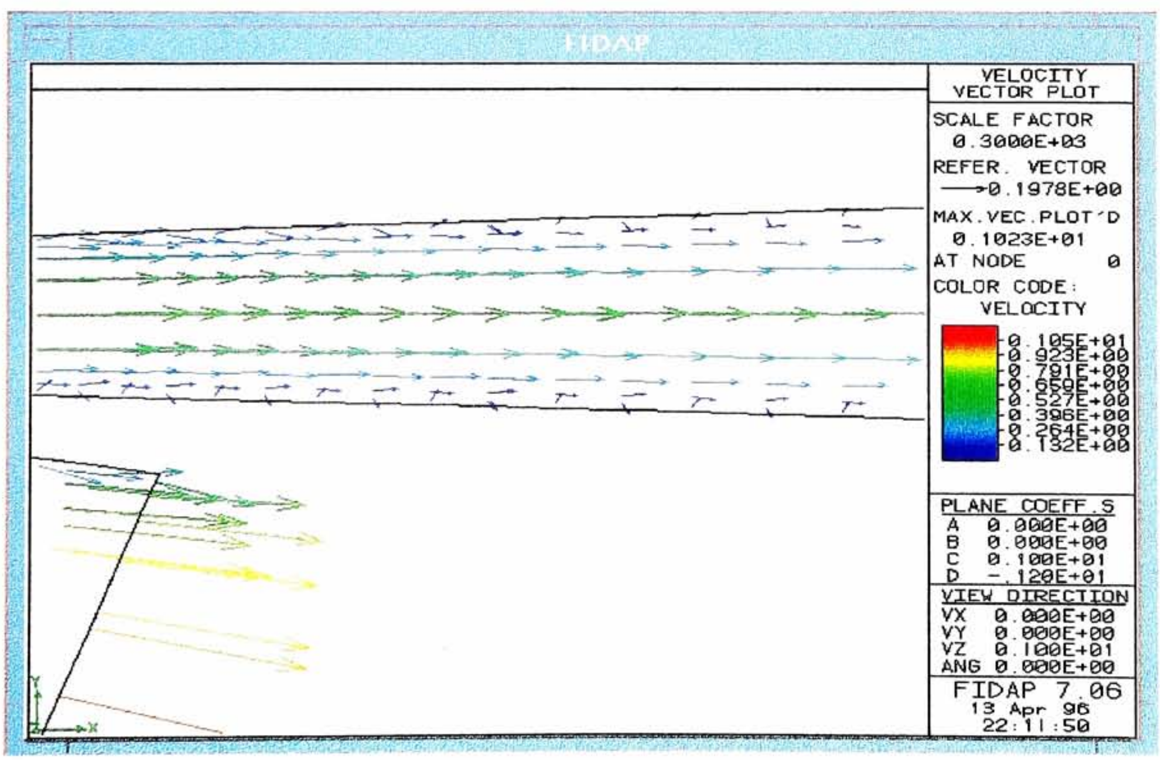


Figure 164 - Velocity at Diffuser's Outlet on Shroud Side (20% - 10%)

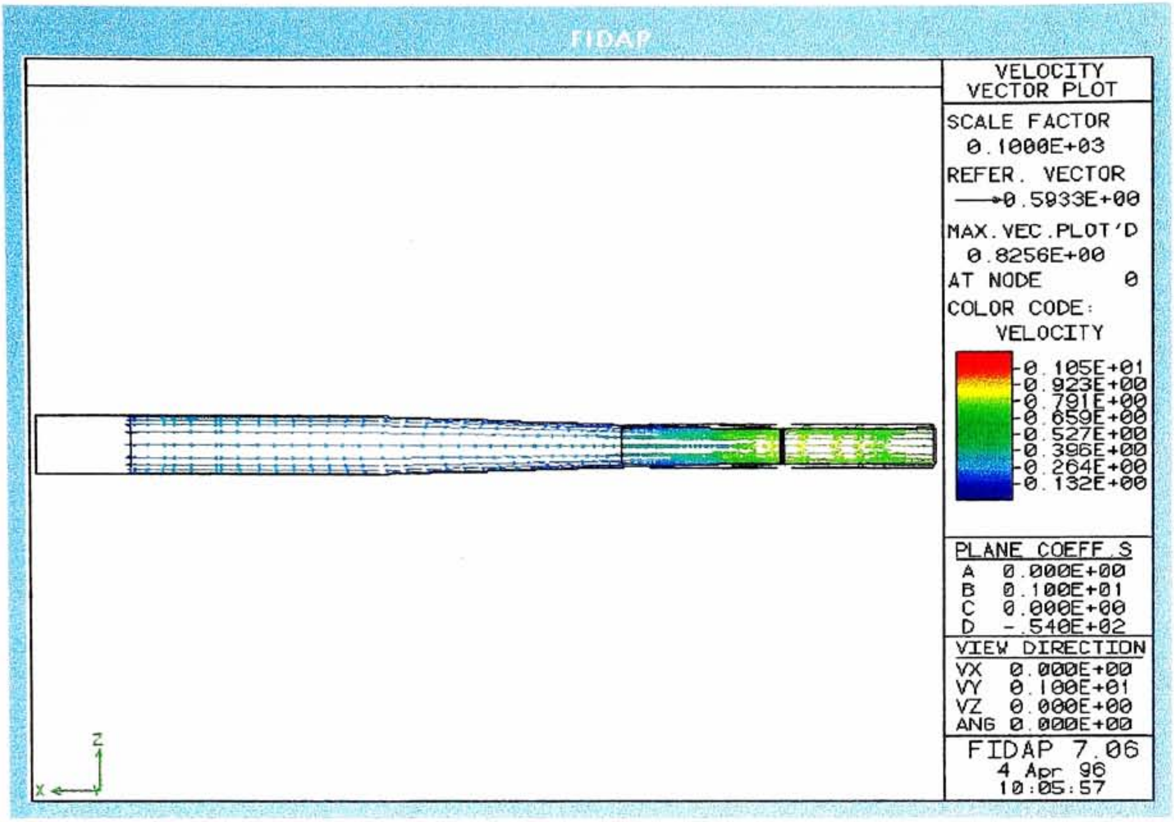


Figure 165 - 2-D View of Velocity on Bottom (20% - 10%)

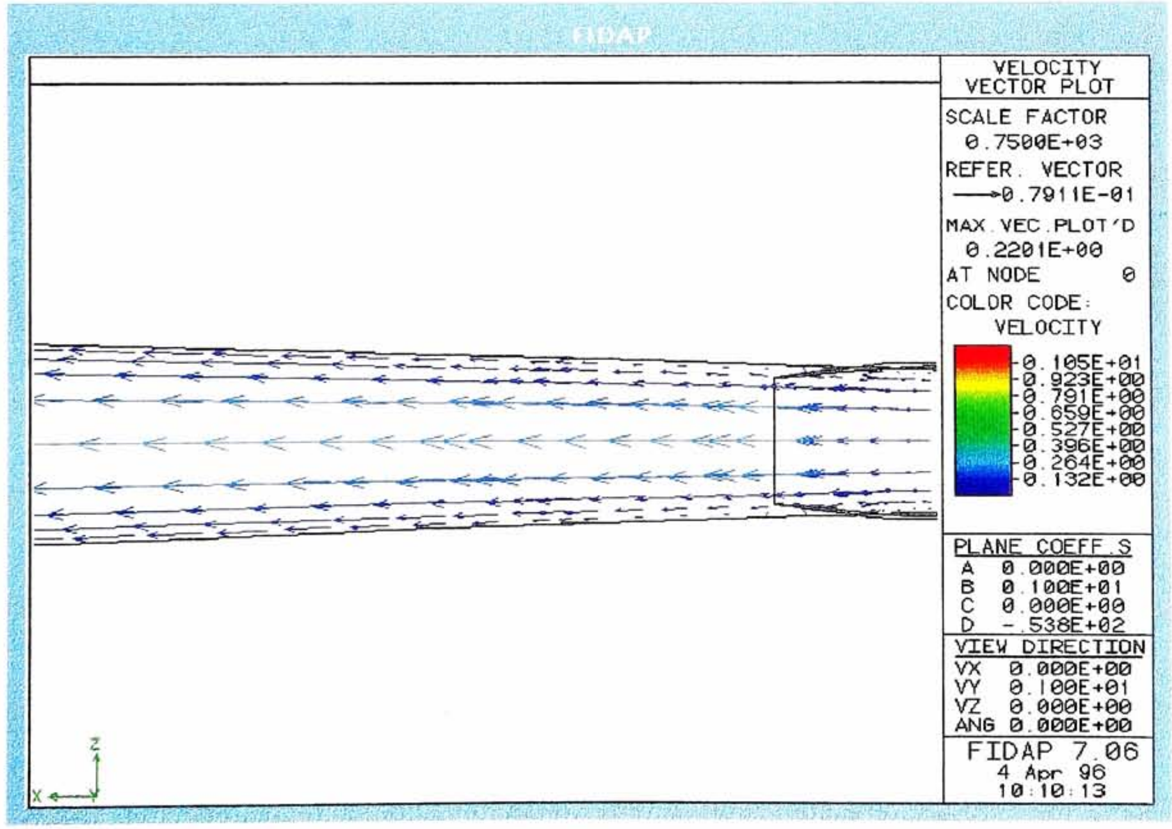


Figure 166 - Close Up of Velocity at Outlet on Bottom (20% - 10%)

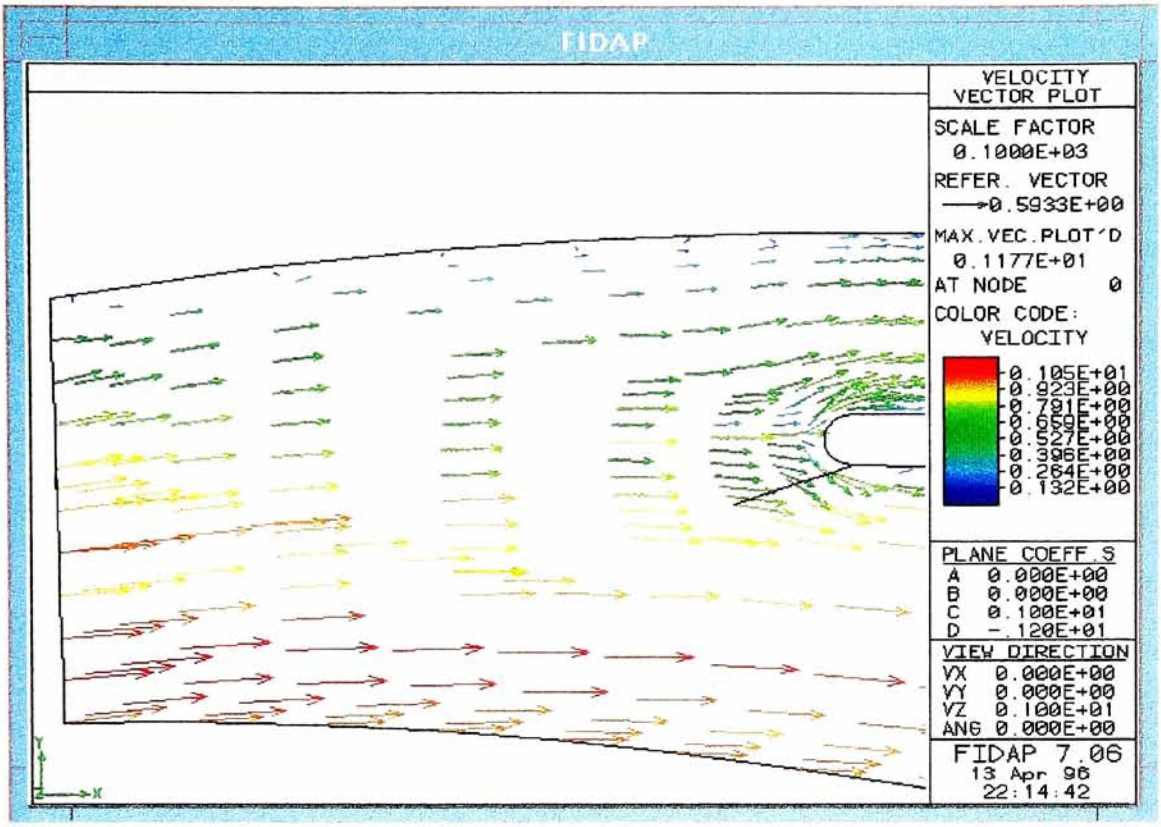


Figure 167 - Velocity at Inlet on Shroud Side (20% - 10%)

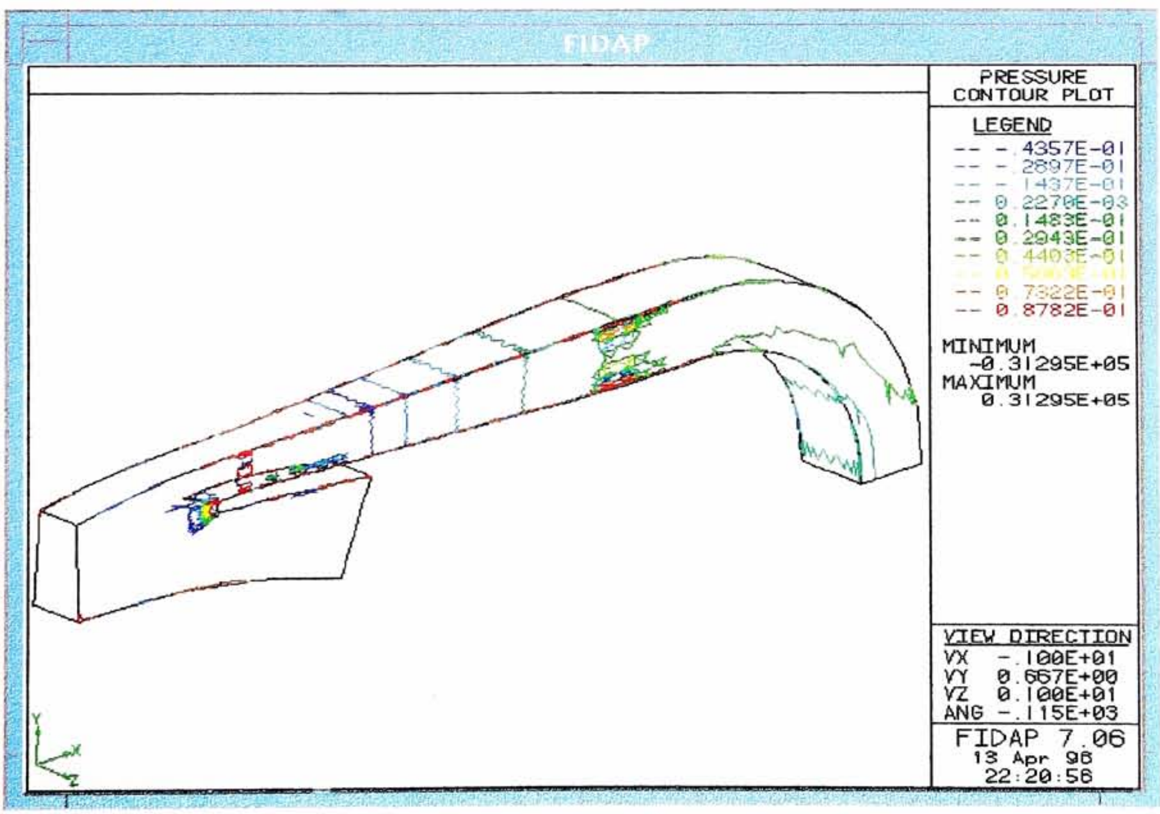


Figure 168 - Pressure Contour Plot (20% - 10%)

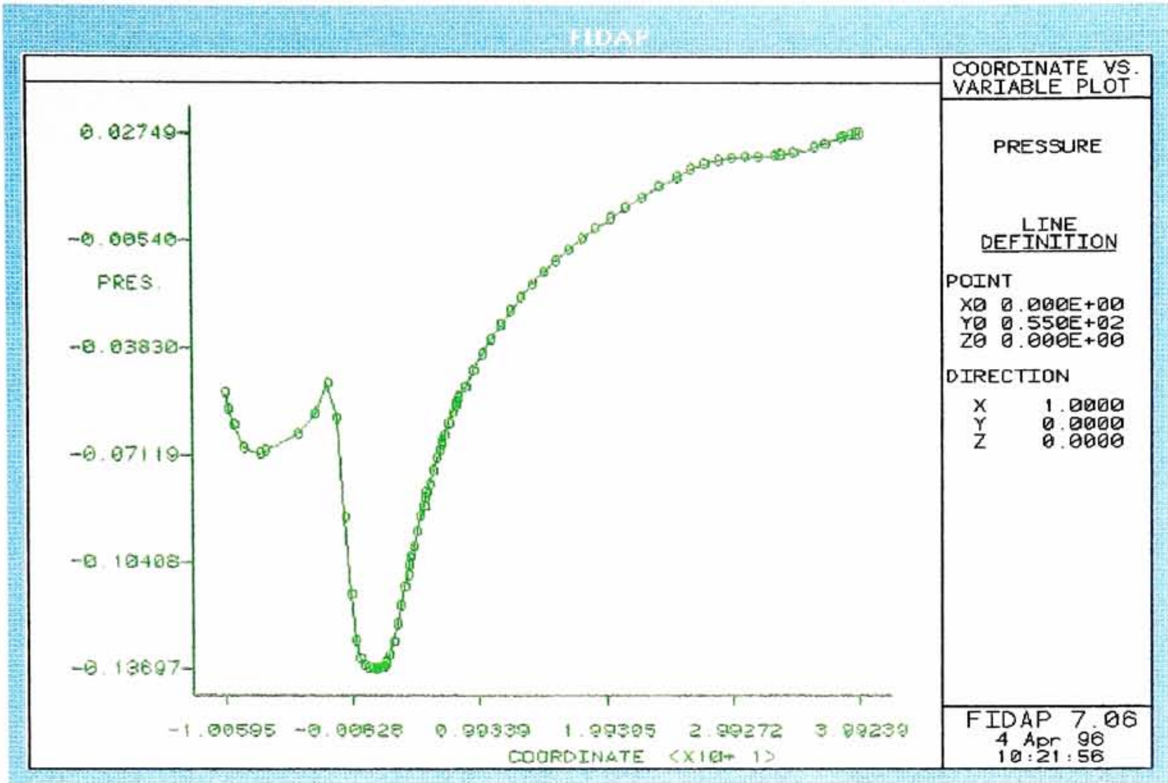


Figure 169 - Pressure Along the Centerline (20% - 10%)

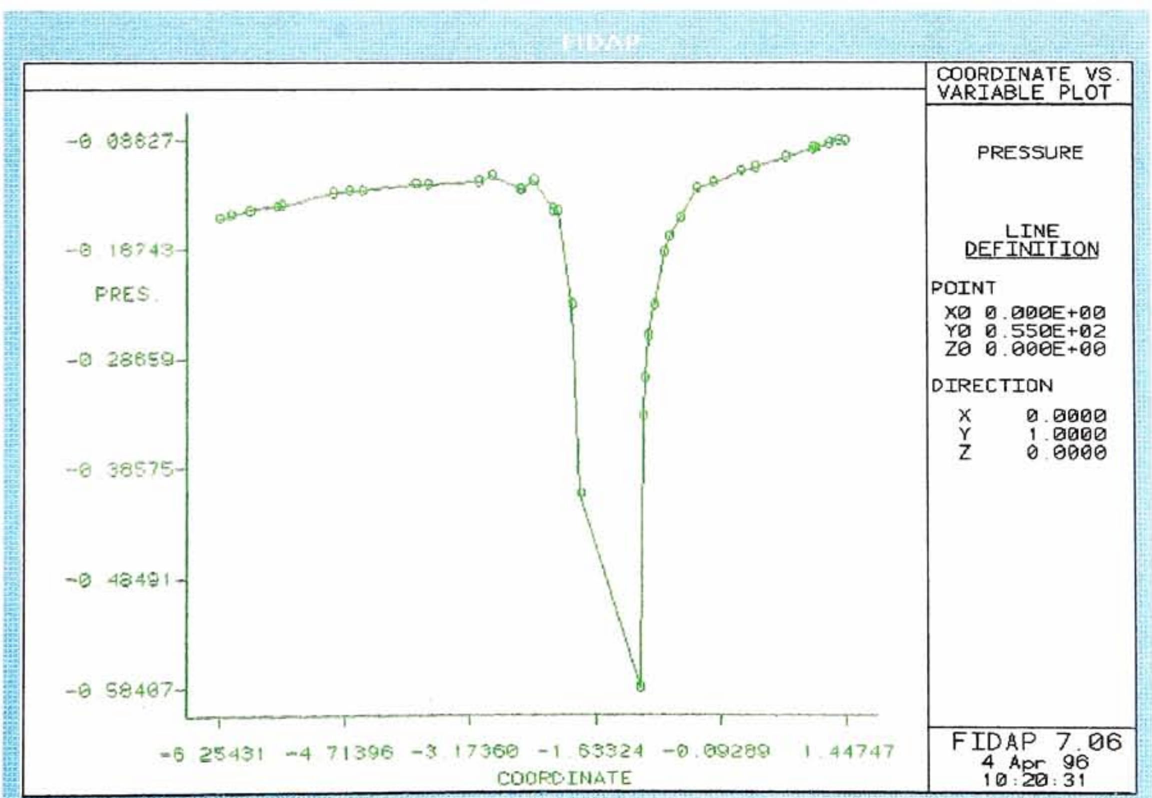


Figure 170 - Inlet Pressure (20% - 10%)

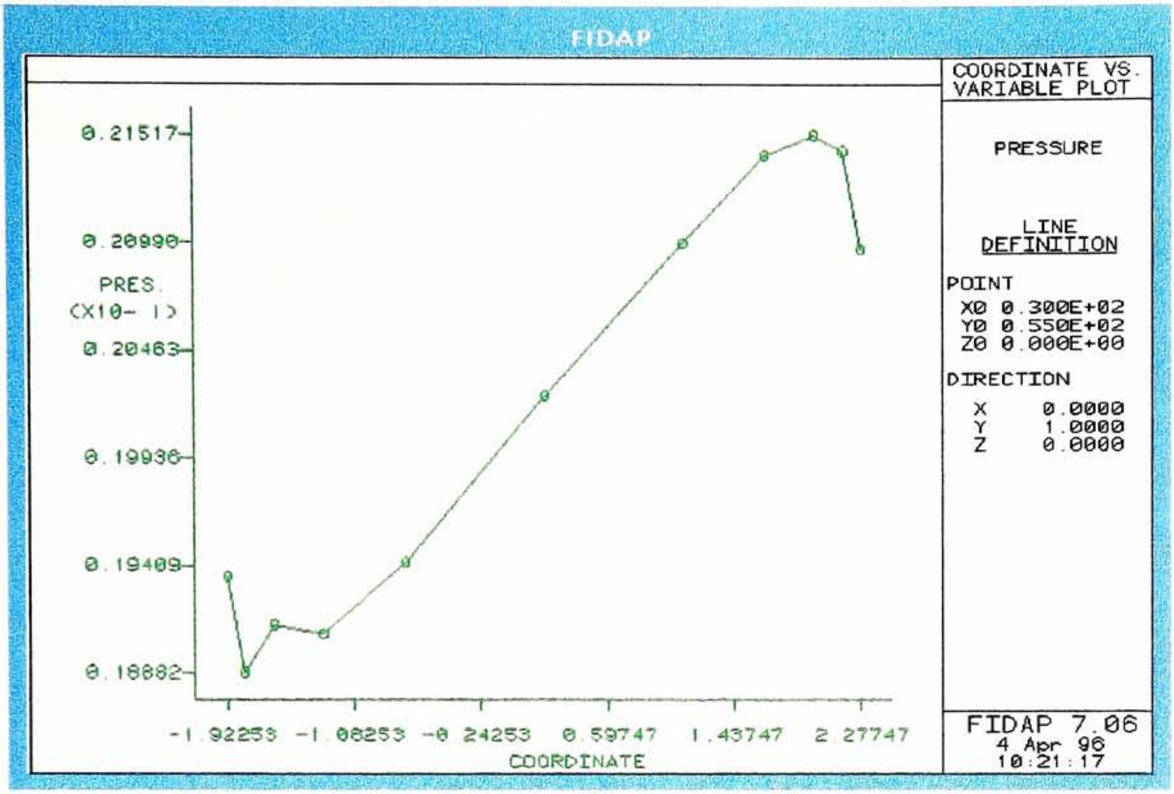


Figure 171 - Outlet Pressure (20% - 10%)

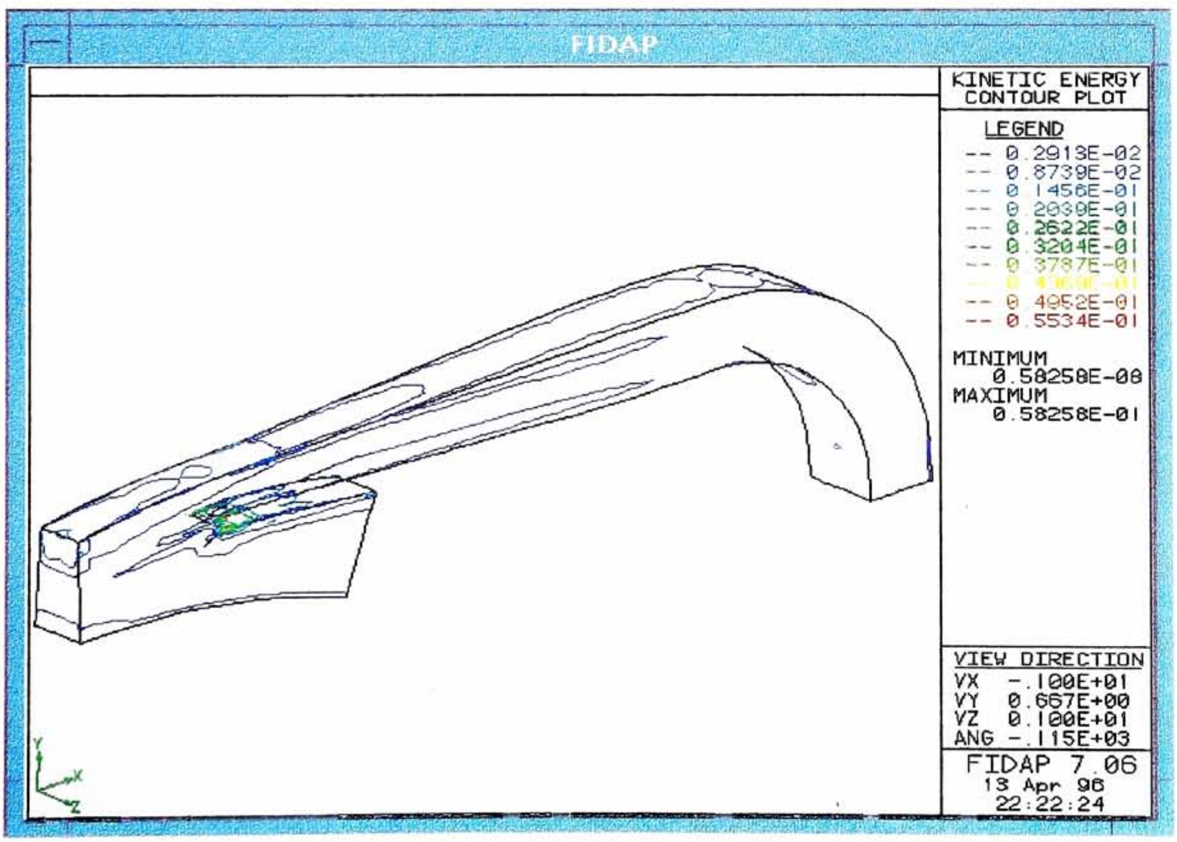


Figure 172 - Kinetic Energy Contour Plot (20% - 10%)

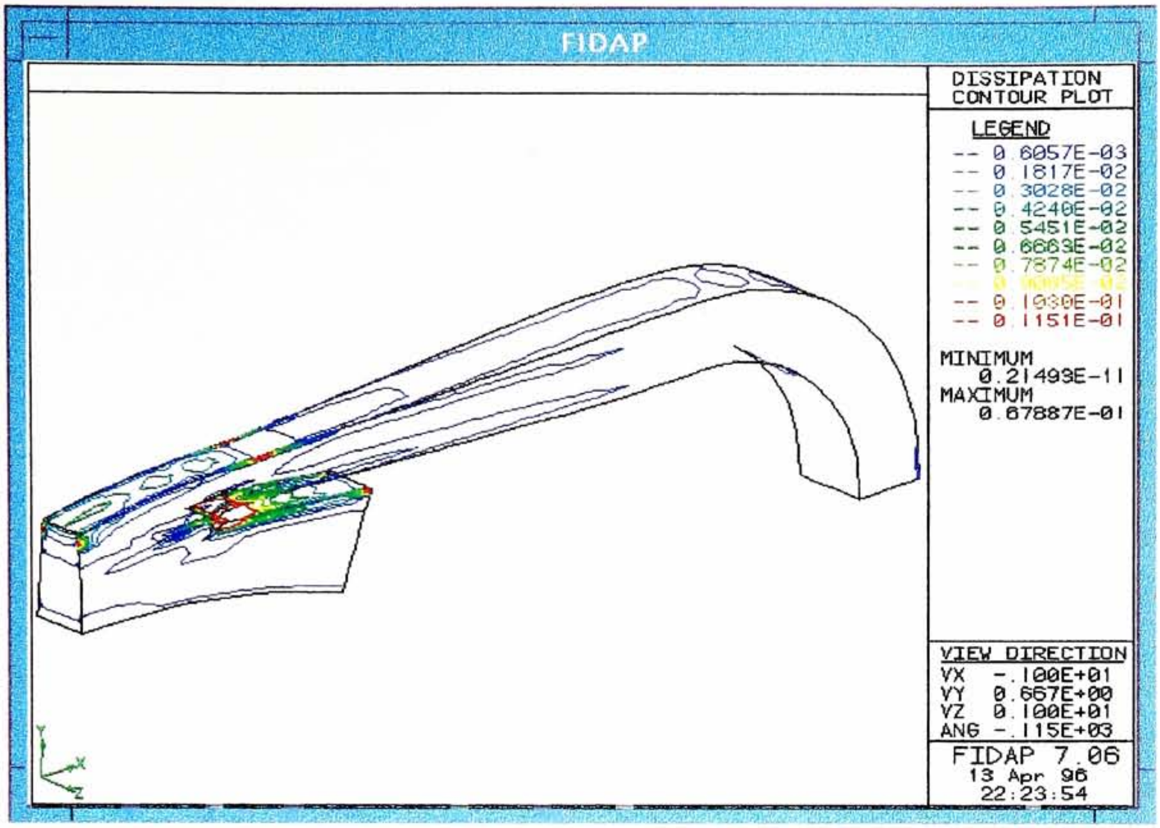


Figure 173 - Dissipation Contour Plot (20% - 10%)

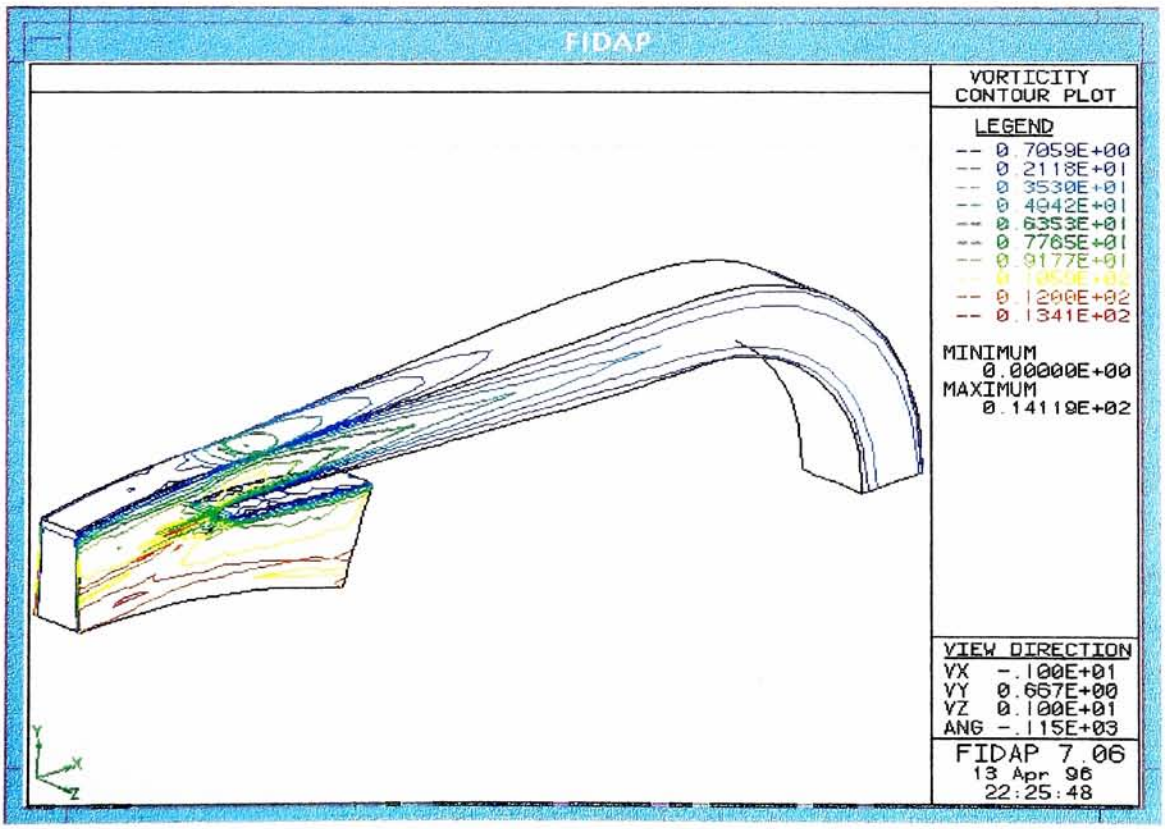


Figure 174 - Vorticity Contour Plot (20% - 10%)

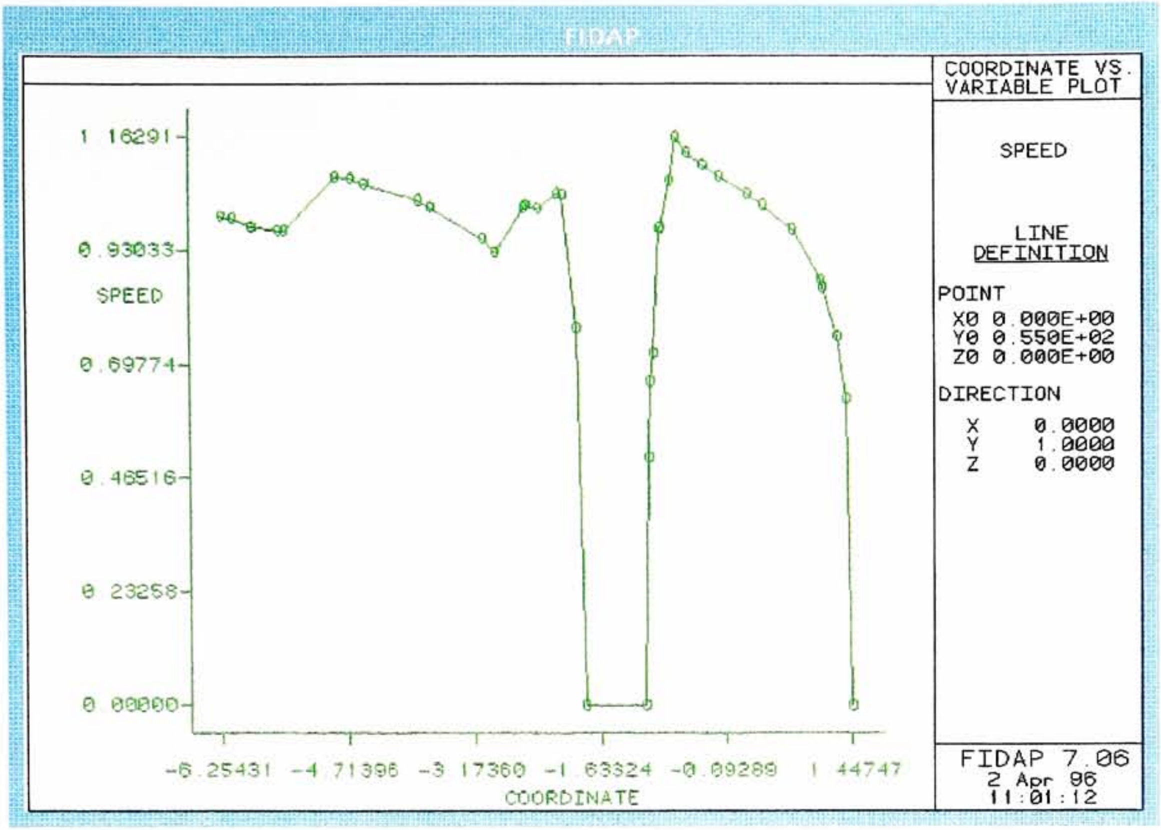


Figure 175 - Inlet Velocity Profile (20% - 10%)

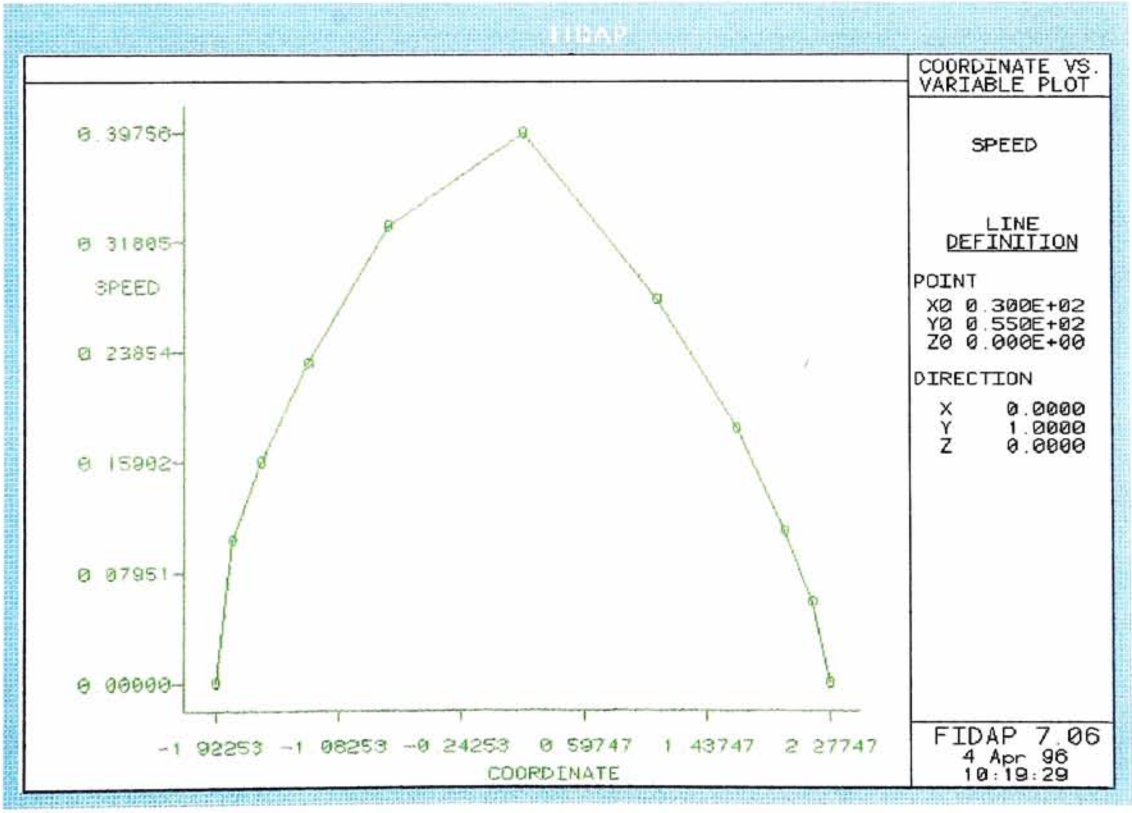


Figure 176 - Outlet Velocity Profile (20% - 10%)

CHAPTER 9.0 CONCLUSIONS.

The purpose of this Thesis was to analyze the behavior of the MK49-F turbopump diffuser at different flow rates and to use fluid injection as a method of boundary layer control. As these results show, flow separation and diffuser stall are inversely proportional to the decrease in the design flow rate. As the design flow rate decreases, the separation and diffuser stall increases. The results of the computational model showed that separation occurs at off-design flow conditions and that fluid injection it is a reliable method to control boundary layer separation. From the results several conclusions can be made:

1. The design flow case does not have any flow separation although it could be observed that there is an area of reduced velocity all along the bottom plane near the shroud side, caused by the conditions of the flow in the diffuser's vaneless region.

2. The Off-Design model for 60% of design flow produced a large region of flow separation and diffuser stall in the bottom plane near the shroud side. As expected, the flow separation and diffuser stall was incremented in the model for the 20% of design flow.This is the same region where the velocity reduction was observed for the design flow model. This flow situation allowed for the application of fluid injection as a means of controlling boundary layer effects.

3. The application of fluid injection through the bottom plane of the diffuser wall was demonstrated to be an effective method for controlling flow separation in a turbopump diffuser.

4. Two-dimensional modeling of the diffuser in FIDAP recommended an injection angle of zero degrees with the diffuser's horizontal plane but the results obtained, during the research stage of this Thesis, using this angle at different injection flow rates were not satisfactory.

5. Different injection angles were used, during the research period of this Thesis, obtaining the best results with an angle of 35 degrees. The fluid injection flow rate varied between 3% and 10%.

6. For the 60% of design flow case, fluid injection of 3% was enough to improve the diffuser's pressure recovery coefficient from 0.56 to 0.6776. Fluid injection of 7% and 10% were also tried and resulted in a decrease in the diffuser's pressure recovery coefficient. An optimum fluid injection rate between 3% and 7% would be probably most effective in eliminating diffuser stall at 60% of design flow.

7. For the 20% of design flow case, fluid injection of 3% improved substantially the diffuser's performance. Fluid injection of 7% improved the diffuser's pressure recovery coefficient even more, from 0.50 to 0.639. As with the 60% of design flow case, fluid injection of 10% was impractical, reduced the diffuser's performance and incremented the amount of flow separation both at the top and bottom planes of the diffuser.

8. It is the conclusion of this Thesis that fluid injection can be used as an effective means of boundary layer control in eliminating flow separation and diffuser stall with the additional advantage of improved diffuser performance.

9. Recommendations for future work would be:

1. Application of fluid injection at the design flow rate in order to eliminate the area of reduced velocity and to improve the performance of the diffuser.
2. Investigate possible methods to reduce the separation at the diffuser's entrance region that affects the overall performance of the diffuser.

3. A more exact determination of what the optimum fluid injection rate is for each case.

CHAPTER 8. SUMMARY OF RESULTS.

The following section summarizes the results obtained in this Thesis. To do this a plot of the Pressure Recovery Coefficient of the Diffuser versus the Amount of Fluid being Injected and a Results Table were used.

The first plot shows what is the effect of the fluid injection for the 20% of Design Flow Case and for the 60% of the Design Flow Case. As it can be seen, the result are different for each flow case. For the 60% Flow Case, the best results are obtained when using a fluid injection of 3% of the Design Flow and for the 20% Flow Case the best results were obtained when using a fluid injection of 7% of the Design Flow. The reason for this is that the amount of fluid separation is larger in the 20% of Design Flow Case and therefore a larger amount of fluid injection is be required.

This plot also proves the effects of very large fluid injections. In both cases, the value of the Pressure Recovery Coefficient, Cp, decreases significantly as we approach a fluid injection of 10% of the Design Flow.

The Pressure Recovery Characteristics Table shows these results in a tabulated manner. In this Table, we can see the value of the Reynolds Number, the Dimensionless Average Pressure at the Inlet of the Diffuser, the Dimensionless Average Pressure at the Outlet of the Diffuser, the Pressure Recovery Coefficient and the Efficiency of the Diffuser. One more time, we can see how the best results are obtained when the amount of fluid injection is 3% for the 60% of the Design Flow Case and 7% for the 20% of the Design Flow Case.

Fluid Injection vs Cp

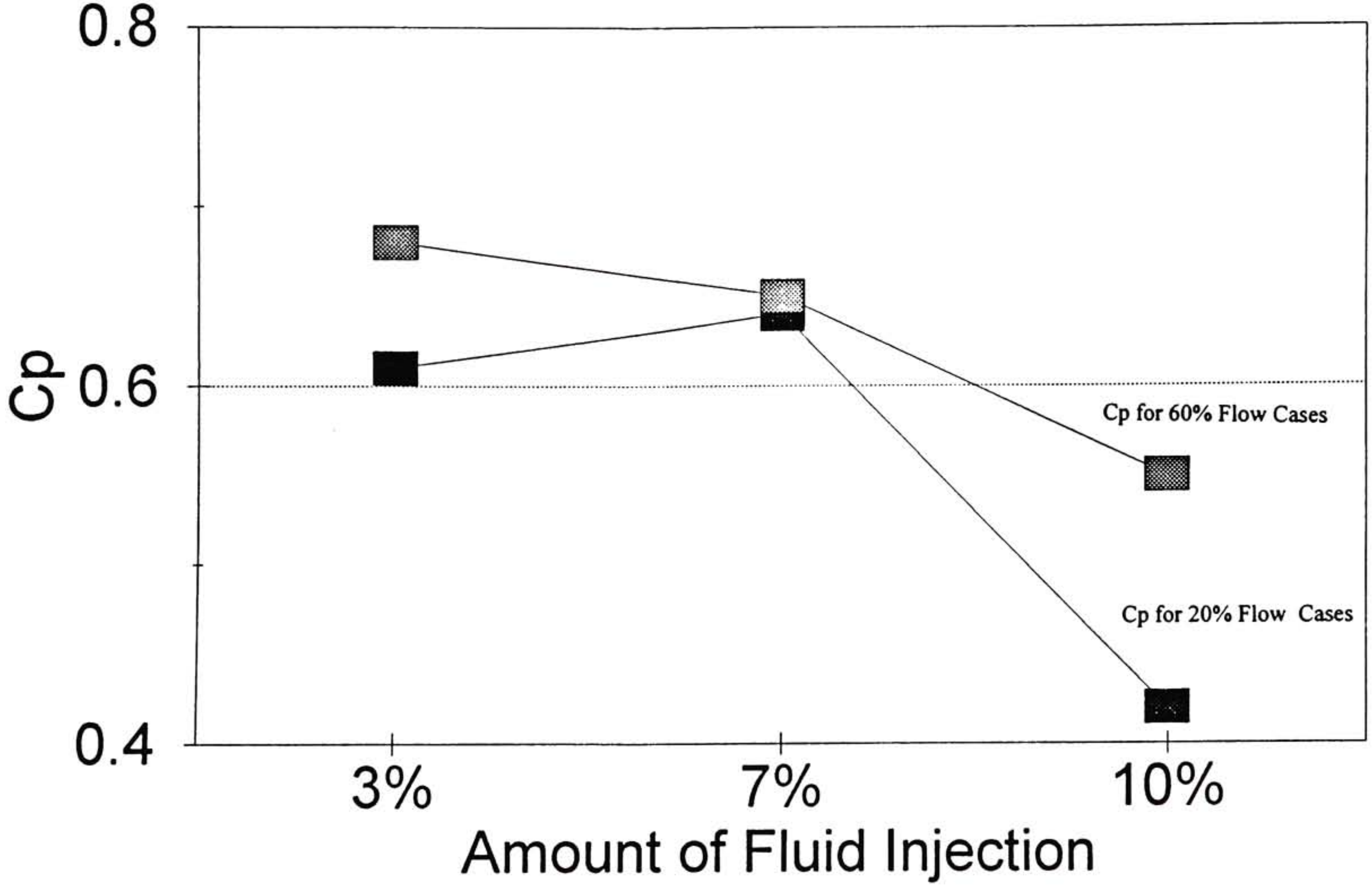


Table B1

Pressure Recovery Characteristics

Model	Re_D	Pi^*	Po^*	Cp	η
Ideal Flow				0.87	1.00
100% Flow	3.0743e5	-0.31	0.007	0.63	0.72
60% Flow	1.8446e5	-0.27	0.0075	0.56	0.64
20% Flow	6.5217e4	-0.238	0.009	0.50	0.57
60%-3% Flow	1.8446e5	-0.319	0.019	0.68	0.78
60%-7% Flow	1.8446e5	-0.305	0.02	0.65	0.75
60%-10% Flow	1.8446e5	-0.248	0.027	0.55	0.63
20%-3% Flow	6.5217e4	-0.285	0.018	0.61	0.70
20%-7% Flow	6.5217e4	-0.302	0.019	0.64	0.74
20%-10% Flow	6.5217e4	-0.19	0.02	0.42	0.48

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APPENDIX A.

DIFFUSER FLOW CONDITIONS.

This appendix describes the flow constants and decribes how the flow conditions for the design, o⌣̀ design and boundary layer control models were determined.

Flow Constants.

$$\text{LH2: } \rho = 0.2455\frac{\text{kg}}{\text{m}^3} \quad \mu = 4.27\text{e}^{-6}\frac{\text{N sec}}{\text{m}^2}$$

Design Flow Rate

$$Q_{\text{diffuser}} = 1.62\text{e}^{-3}\frac{\text{m}^3}{\text{sec}}$$

$$V_{2\text{m}} = 29.348\frac{\text{m}}{\text{sec}}$$

$$V_{2\theta} = 517.71294\frac{\text{m}}{\text{sec}}$$

$$\text{m}_{\text{inlet}} = 3.9771\text{e}^{-4}\frac{\text{kg}}{\text{sec}}$$

$$\text{Re}_{\text{d}} = 3.0743\text{e}^{5}$$

60% Design Flow Rate

$$Q_{\text{diffuser}} = 9.72\text{e}^{-4}\frac{\text{m}^3}{\text{sec}}$$

$$V_{2\text{m}} = 17.609\frac{\text{m}}{\text{sec}}$$

$$V_{2\theta} = 540.045\frac{\text{m}}{\text{sec}}$$

$$\text{m}_{\text{inlet}} = 2.3863\text{e}^{-4}\frac{\text{kg}}{\text{sec}}$$

$$\text{Re}_{\text{d}} = 1.8446\text{e}^{5}$$

20% Design Flow Rate

$$Q_{diffuser} = 3.24e^{-4}\,\frac{m^3}{sec}$$

$$V_{2m} = 6.2308\,\frac{m}{sec}$$

$$V_{2\theta} = 553.43\,\frac{m}{sec}$$

$$m_{inlet} = 7.9542e^{-5}\,\frac{kg}{sec}$$

$$Re_d = 6.5217e^4$$

APPENDIX B

DETERMINATION OF THE PRESSURE RECOVERY COEFFICIENT

The pressure recovery coefficient, C_p , is defined by,

$$C_p = \frac{\Delta P}{\frac{1}{2}\rho \upsilon^2} \qquad \text{(Eq. B1)}$$

where: ΔP = change in pressure across the diffuser

ρ = fluid density (assumed constant)

υ = inlet velocity

Because the solution method used required the fluid characteristics to be nondimensionalized, the nondimensionalized pressure defined by FIDAP is,

$$P^{*} = \frac{P}{\rho \upsilon^2} \qquad \text{(Eq. B2)}$$

where the dimensional pressure, upon rearrangement is,

$$P = P^{*} \rho \upsilon^2 \qquad \text{(Eq. B3)}$$

which upon substitution gives the pressure recovery coefficient as a function of P^{*} :

$$C_p = 2\Delta P^{*} = 2(P_o^{*} - P_i^{*}) \qquad \text{(Eq. B4)}$$

The inlet and outlet pressures, P_i^{*} and P_o^{*}, were calculated using the line pressure plots shown in the result section. The following pages show the values of these plots for one of the cases and how the average values were calculated.

= 9 , PARALLEL TO EXISTING LINE THROUGH POINT
=10 , PERPENDICULAR TO EXISTING PLANE THROUGH NODE
=11 , PERPENDICULAR TO EXISTING PLANE THROUGH POINT
=12 , LIST OF NODES
=13 , BOUNDARY ELEMENT GROUP
=20 , INTERACTIVE SELECTION

LINE DEFINITION

POINT (X COORDINATE) . . . . (POINT(1))=0.0000E+00

POINT (Y COORDINATE) . . . . (POINT(2))=0.5500E+02

POINT (Z COORDINATE) . . . . (POINT(3))=0.0000E+00

VECTOR (X COMPONENT) . . . . (VECTOR(1)=0.0000E+00

VECTOR (Y COMPONENT) . . . . (VECTOR(2)=0.1000E+01

VECTOR (Z COMPONENT) . . . . (VECTOR(3)=0.0000E+00

RESULTING LINE : POINT : 0.0000E+00 0.5500E+02 0.0000E+00
DIRECTION : 0.0000 1.0000 0.0000

POINT	COORDINATE	VALUE
1	-.62543E+01	-.15058E+00
2	-.61142E+01	-.14827E+00
3	-.58792E+01	-.14367E+00
4	.55511E+01	-.13973E+00
5	-.54889E+01	-.13881E+00
6	-.48585E+01	-.12782E+00
7	-.46622E+01	-.12578E+00
8	-.45038E+01	-.12531E+00
9	.38431E+01	-.11949E+00
10	-.36980E+01	-.11945E+00
11	-.30674E+01	-.11592E+00
12	-.29063E+01	-.11133E+00
13	-.25650E+01	-.11831E+00
14	-.25412E+01	-.11850E+00
15	-.23900E+01	-.11111E+00
16	-.21612E+01	-.12905E+00
17	-.20960E+01	-.12793E+00
18	-.19249E+01	-.19004E+00
19	-.18225E+01	-.34054E+00
20	-.10925E+01	-.87540E+00
21	-.10531E+01	-.52503E+00
22	-.10319E+01	-.48180E+00
23	-.99184E+00	-.42682E+00
24	-.91773E+00	-.38927E+00
25	-.91053E+00	-.38762E+00
26	-.78753E+00	-.32045E+00
27	-.72023E+00	-.30233E+00
28	-.57927E+00	-.27605E+00
29	-.38666E+00	-.23949E+00
30	-.18524E+00	-.23215E+00

```
     31       0.16314E+00      -.22159E+00
     32       0.34683E+00      -.21758E+00
     33       0.71642E+00      -.20411E+00
     34       0.10532E+01      -.18726E+00
     35       0.10788E+01      -.18649E+00
     36       0.12538E+01      -.17599E+00
     37       0.13735E+01      -.16831E+00
     38       0.14475E+01      -.16160E+00

***   0.796 COMMAND EXECUTION TIME


N O D A L  -  C O O R D I N A T E  P L O T
==========================================

        NODAL DEGREE OF FREEDOM  . . . . . . . . . . . . . . . . . . . (NDEG)    =          5
            = 1 , X COMPONENT OF VELOCITY , U
            = 2 , Y COMPONENT OF VELOCITY , V
            = 3 , Z COMPONENT OF VELOCITY , W
            = 4 , SPEED ( SQRT(U*U+V*V+W*W) )
            = 5 , PRESSURE
            = 6 , TEMPERATURE
            = 7 , TURBULENT KINETIC ENERGY
            = 8 , TURBULENT DISSIPATION
            = 9 , STREAMLINE
            =10 , VORTICITY
            =11 , USER DEFINED VARIABLE
            =12 , X COORDINATE
            =13 , Y COORDINATE
            =14 , Z COORDINATE
            =15 , TURBULENT VISCOSITY
            =16 , NON-NEWTONIAN VISCOSITY
            =18 , RESIDENCE
            =19 , DENSITY
            =20 , CELL REYNOLDS NO.
            =21 , USER VECTOR FUNCTION MAGNITUDE
            =22 , SHEAR RATE
            =23 , FLUX (3-D ONLY)
            =24 , FLOWRATE (3-D ONLY)
            =25 , COEFFICIENT (3-D ONLY)
            =26 , STRESS MAGNITUDE (3-D ONLY)
            =27 , CELL PECLET NO.
            =28 , MACH NUMBER
            =29 , TRANSFORMED VARIABLE
            =30 , PROPERTY
            =31 , SPECIES 1
            =45 , SPECIES 15

        LINE DEFINITION OPTION FLAG  . . . . . . . . . . . . . . . . . (LTYPE)   =          2
            < 0 , PREVIOUS LINE, OPPOSITE DIRECTION
            = 1 , NODAL POINT AND A VECTOR
            = 2 , POINT AND A VECTOR
            = 3 , TWO NODAL POINTS
            = 4 , TWO POINTS
            = 5 , THREE NODAL POINTS
            = 6 , THREE POINTS
            = 7 , LINE COEFFICIENTS
            _ 8 , PARALLEL TO EXISTING LINE THROUGH NODE
            = 9 , PARALLEL TO EXISTING LINE THROUGH POINT
            =10 , PERPENDICULAR TO EXISTING PLANE THROUGH NODE
```

```
=11 , PERPENDICULAR TO EXISTING PLANE THROUGH POINT
=12 , LIST OF NODES
=13 , BOUNDARY ELEMENT GROUP
=20 , INTERACTIVE SELECTION
```

LINE DEFINITION

```
POINT (X COORDINATE) . . . . . . . . . . . . . . . . . . (POINT(1))=0.0000E+00

POINT (Y COORDINATE) . . . . . . . . . . . . . . . . . . (POINT(2))=0.5500E+02

POINT (Z COORDINATE) . . . . . . . . . . . . . . . . . . (POINT(3))=0.0000E+00

VECTOR (X COMPONENT) . . . . . . . . . . . . . . . . . . (VECTOR(1)=0.1000E+01

VECTOR (Y COMPONENT) . . . . . . . . . . . . . . . . . . (VECTOR(2)=0.0000E+00

VECTOR (Z COMPONENT) . . . . . . . . . . . . . . . . . . (VECTOR(3)=0.0000E+00

RESULTING LINE  :  POINT      :   0.0000E+00  0.5500E+02  0.0000E+00
                   DIRECTION :       1.0000      0.0000      0.0000
```

POINT	COORDINATE	VALUE
1	-.10059E+02	-.79127E-01
2	-.97874E+01	-.82635E-01
3	-.93290E+01	-.84486E-01
4	-.85554E+01	-.89353E-01
5	-.72445E+01	-.91345E-01
6	-.68486E+01	-.90673E-01
7	-.43271E+01	-.87244E-01
8	-.29511E+01	-.85158E-01
9	-.29315E+01	-.85073E-01
10	-.19781E+01	-.82235E-01
11	-.12607E+01	-.10909E+00
12	-.67582E+00	-.16583E+00
13	-.15477E+00	-.21106E+00
14	0.16858E+00	-.24151E+00
15	0.49666E+00	-.25528E+00
16	0.82446E+00	-.26374E+00
17	0.11494E+01	-.26885E+00
18	0.14691E+01	-.27249E+00
19	0.17780E+01	-.27449E+00
20	0.18415E+01	-.27389E+00
21	0.19050E+01	-.27172E+00
22	0.20743E+01	-.27204E+00
23	0.22437E+01	-.27232E+00
24	0.24130E+01	-.27242E+00
25	0.24765E+01	-.26910E+00
26	0.25400E+01	-.26615E+00
27	0.28363E+01	-.26350E+00
28	0.31327E+01	-.25774E+00
29	0.34290E+01	-.24991E+00
30	0.37253E+01	-.24119E+00
31	0.40217E+01	-.23257E+00
32	0.43180E+01	-.22707E+00

33	0.43815E+01	-.22074E+00
34	0.44450E+01	.21528E+00
35	0.47308E+01	-.21038E+00
36	0.50165E+01	-.20224E+00
37	0.53022E+01	-.19427E+00
38	0.55880E+01	-.18915E+00
39	0.56515E+01	-.18483E+00
40	0.57150E+01	-.18202E+00
41	0.60008E+01	-.17707E+00
42	0.62865E+01	-.16888E+00
43	0.65722E+01	-.16090E+00
44	0.68580E+01	-.15587E+00
45	0.69215E+01	-.15341E+00
46	0.69850E+01	-.15296E+00
47	0.72708E+01	-.14824E+00
48	0.75565E+01	-.14018E+00
49	0.78422E+01	-.13252E+00
50	0.81280E+01	-.12790E+00
51	0.81915E+01	-.12714E+00
52	0.82550E+01	-.12547E+00
53	0.88694E+01	-.11776E+00
54	0.95146E+01	-.10535E+00
55	0.10192E+02	-.95052E-01
56	0.10903E+02	-.85365E-01
57	0.11650E+02	-.76185E-01
58	0.12434E+02	-.67401E-01
59	0.13258E+02	-.59039E-01
60	0.14122E+02	-.51036E-01
61	0.15030E+02	-.43415E-01
62	0.15983E+02	-.36117E-01
63	0.16984E+02	-.29158E-01
64	0.18035E+02	-.22484E-01
65	0.19138E+02	-.16115E-01
66	0.20297E+02	-.99938E-02
67	0.21513E+02	-.41685E-02
68	0.22791E+02	0.14277E-02
69	0.24132E+02	0.67647E-02
70	0.25540E+02	0.11121E-01
71	0.26617E+02	0.14680E-01
72	0.27693E+02	0.16703E-01
73	0.28770E+02	0.18148E-01
74	0.29847E+02	0.19205E-01
75	0.30920E+02	0.19860E-01
76	0.31999E+02	0.20296E-01
77	0.33303E+02	0.20940E-01
78	0.33728E+02	0.21393E-01
79	0.34766E+02	0.22583E-01
80	0.36453E+02	0.25627E-01
81	0.37243E+02	0.27520E-01
82	0.38462E+02	0.31250E-01
83	0.38636E+02	0.31945E-01
84	0.39294E+02	0.34599E-01
85	0.39688E+02	0.36406E-01
86	0.39924E+02	0.37203E-01

*** 0.858 COMMAND EXECUTION TIME

N O D A L - C O O R D I N A T E P L O T
===

```
NODAL DEGREE OF FREEDOM . . . . . . . . . . . . . . . . . . (NDEG)    =          5
    = 1 , X COMPONENT OF VELOCITY , U
    = 2 , Y COMPONENT OF VELOCITY , V
    = 3 , Z COMPONENT OF VELOCITY , W
    = 4 , SPEED ( SQRT(U*U+V*V+W*W) )
    = 5 , PRESSURE
    = 6 , TEMPERATURE
    = 7 , TURBULENT KINETIC ENERGY
    = 8 , TURBULENT DISSIPATION
    = 9 , STREAMLINE
    =10 , VORTICITY
    =11 , USER DEFINED VARIABLE
    =12 , X COORDINATE
    =13 , Y COORDINATE
    =14 , Z COORDINATE
    =15 , TURBULENT VISCOSITY
    =16 , NON-NEWTONIAN VISCOSITY
    =18 , RESIDENCE
    =19 , DENSITY
    =20 , CELL REYNOLDS NO.
    =21 , USER VECTOR FUNCTION MAGNITUDE
    =22 , SHEAR RATE
    =23 , FLUX (3-D ONLY)
    =24 , FLOWRATE (3-D ONLY)
    =25 , COEFFICIENT (3-D ONLY)
    =26 , STRESS MAGNITUDE (3-D ONLY)
    =27 , CELL PECLET NO.
    =28 , MACH NUMBER
    =29 , TRANSFORMED VARIABLE
    =30 , PROPERTY
    -31 , SPECIES 1
    =45 , SPECIES 15

LINE DEFINITION OPTION FLAG . . . . . . . . . . . . . . . . (LTYPE)   =          2
    < 0 , PREVIOUS LINE, OPPOSITE DIRECTION
    = 1 , NODAL POINT AND A VECTOR
    = 2 , POINT AND A VECTOR
    = 3 , TWO NODAL POINTS
    = 4 , TWO POINTS
    = 5 , THREE NODAL POINTS
    = 6 , THREE POINTS
    = 7 , LINE COEFFICIENTS
    = 8 , PARALLEL TO EXISTING LINE THROUGH NODE
    = 9 , PARALLEL TO EXISTING LINE THROUGH POINT
    =10 , PERPENDICULAR TO EXISTING PLANE THROUGH NODE
    =11 , PERPENDICULAR TO EXISTING PLANE THROUGH POINT
    =12 , LIST OF NODES
    =13 , BOUNDARY ELEMENT GROUP
    =20 , INTERACTIVE SELECTION


LINE DEFINITION
---------------


POINT (X COORDINATE) . . . . . . . . . . . . . . . . . . (POINT(1))=0.3000E+02

POINT (Y COORDINATE) . . . . . . . . . . . . . . . . . . (POINT(2))=0.5500E+02
```

```
        POINT (Z COORDINATE) . . . . . . . . . . . . . . . . . . . (POINT(3))=0.0000E+00

        VECTOR (X COMPONENT) . . . . . . . . . . . . . . . . . . . (VECTOR(1)=0.0000E+00

        VECTOR (Y COMPONENT) . . . . . . . . . . . . . . . . . . . (VECTOR(2)=0.1000E+01

        VECTOR (Z COMPONENT) . . . . . . . . . . . . . . . . . . . (VECTOR(3)=0.0000E+00

RESULTING LINE  :  POINT      :   0.3000E+02  0.5500E+02  0.0000E+00
                   DIRECTION :       0.0000      1.0000      0.0000

    POINT      COORDINATE          VALUE

      1        -.19225E+01      0.17999E-01
      2        -.18077E+01      0.17551E-01
      3        -.16144E+01      0.17643E-01
      4        -.12889E+01      0.17757E-01
      5        -.74173E+00      0.18381E-01
      6        0.17721E+00      0.19515E-01
      7        0.10969E+01      0.20563E-01
      8        0.16440E+01      0.21135E-01
      9        0.19692E+01      0.21315E-01
     10        0.21626E+01      0.21305E-01
     11        0.22775E+01      0.20940E-01

***    0.786 COMMAND EXECUTION TIME

*** FIPOST RUN COMPLETED (    3 PLOTS) - RETURNING TO FIDAP ROOT LEVEL
```

As an example of how the Pressure Recovery Coefficient was calculated. the 60% - 3% Flow Case will be used. To calculate it. the inlet and outlet pressure plots were used. The values of the pressure plots are recorded by FIDAP in the FIPOST file that could be seen in the previous pages. For the inlet pressure the values are:

-0.8754, -0.52503, -0.4818, -0.42682, -0.38927, -0.38762, -0.32045, -0.30233, -0.27605, -0.23949, -0.22259, -0.21758, -0.20411, -0.18726, -0.18649, -0.17599, -0.16831, -0.16160.

The sum of these values comes out to be : -5.74819, and the average value for the pressure at the inlet is calculated to be : -0.3193439

The process is repeated to calculate the pressure at the outlet. The values of the pressure at the outlet are:

0.017999, 0.017551, 0.017643, 0.017757, 0.018381, 0.019515, 0.020563, 0.021135, 0.021315, 0.021305, 0.020940.

The sum of these values comes out to be : 0.214104, and the average value for the pressure at the inlet is calculated to be : 0.019464.

Using Eq. B4, the value of the Pressure Recovery Coefficient comes out to be:

$$C_p = 2\Delta P^* = 2(P_o^* - P_i^*) = 2\ (\ 0.019464 + 0.3193439\ ) = 0.6776158$$

APPENDIX C.

FIDAP INPUT FILES.

60% OF DESIGN FLOW FIDAP INPUT FILE

```
/ File opened for write Thu Dec 21 15:09:58 1995.
////// geometry parameters
/
////// grid along mesh edge
/
//// node number for different mesh
/
/
//// boundary condition for input
/
DEVICE( NOGR )
/
/ This is the geometory file for the MK49F diffuser. This model utilizes no
/ boundary control.
/
////////////// define mesh edge ////////////////
/
///// mesh generation
/
FI-GEN( ELEM = 1, POIN = 1, CURV = 1, SURF - 1, NODE - 0, MEDG = 1, MLOO = 1,
MFAC = 1, BEDG = 1, SPAV = 1, MSHE = 1, MSOL   1 )
WINDOW(CHANGE= 1, MATRIX )
    1.000000    0.000000    0.000000    0.000000
    0.000000    1.000000    0.000000    0.000000
    0.000000    0.000000    1.000000    0.000000
    0.000000    0.000000    0.000000    1.000000
  -10.00000    10.00000    -7.50000     7.50000    -7.50000     7.50000
/
///// setup key points /////////
/
  INT( ADD, SHOW, LABE = "i1", Z = -1.5748, COOR, X - 8.038459342,
Y = 46.59921454 )
POINT( ADD, SHOW, LABE = "zi1", Z = 1.5748, COOR, X = 8.038459342,
Y = 46.59921454 )
POINT( ADD, SHOW, LABE = "i2", Z = -1.5748, COOR, X = -9.928567926,
Y = 49.51589202 )
POINT( ADD, SHOW, LABE = "zi2", Z = 1.5748, COOR, X = -9.928567926,
Y - 49.51589202 )
POINT( ADD, SHOW, LABE = "w1", Z = -1.27, COOR, X = -10.07176483,
Y = 55.51418299 )
POINT( ADD, SHOW, LABE = "zw1", Z = 1.27, COOR, X = -10.07176483,
Y = 55.51418299 )
POINT( ADD, SHOW, LABE = "w2", Z = -1.27, COOR, X - 0, Y = 56.44746945 )
POINT( ADD, SHOW, LABE = "zw2", Z = 1.27, COOR, X = 0, Y = 56.44746945 )
POINT( ADD, SHOW, LABE = "w3", Z = -1.27, COOR, X - 2.54, Y = 56.44746945 )
POINT( ADD, SHOW, LABE - "zw3", Z = 1.27, COOR, X = 2.54, Y = 56.44746945 )
POINT( ADD, SHOW, LABE = "w4", Z = -2.0988, COOR, X = 25.54, Y   57.27746945 )
POINT( ADD, SHOW, LABE = "zw4", Z = 2.0988, COOR, X = 25.54, Y - 57.27746945 )
POINT( ADD, SHOW, LABE = "w5", Z = -2.0988, COOR, X = 31.91, Y = 57.27746945 )
POINT( ADD, SHOW, LABE = "zw5", Z = 2.0988, COOR, X = 31.91, Y   57.27746945 )
POINT( ADD, SHOW, LABE = "w6", Z = -2.0988, COOR, X = 42.87015511,
Y = 52.73762456 )
POINT( ADD, SHOW, LABE = "zw6", Z = 2.0988, COOR, X = 42.87015511,
Y = 52.73762456 )
POINT( ADD, SHOW, LABE = "w7", Z = -2.0988, COOR, X = 47.41, Y = 41.77746945 )
 INT( ADD, SHOW, LABE - "zw7", Z = 2.0988, COOR, X = 47.41, Y - 41.77746945 )
OINT( ADD, SHOW, LABE = "w8", Z = -2.0988, COOR, X = 43.21, Y - 41.77746945 )
POINT( ADD, SHOW, LABE = "zw8", Z = 2.0988, COOR, X = 43.21, Y = 41.77746945 )
POINT( ADD, SHOW, LABE = "w9", Z = -2.0988, COOR, X = 39.90030663,
```

```
Y = 49.76777607 )
POINT( ADD, SHOW, LABE = "zw9", Z = 2.0988, COOR, X = 39.90030663,
Y = 49.76777607 )
POINT( ADD, SHOW, LABE = "w10", Z = -2.0988, COOR, X = 31.91, Y = 53.07746945 )
POINT( ADD, SHOW, LABE = "zw10", Z = 2.0988, COOR, X = 31.91, Y = 53.07746945 )
  INT( ADD, SHOW, LABE = "w11", Z = -2.0988, COOR, X = 25.54, Y = 53.07746945 )
.OINT( ADD, SHOW, LABE - "zw11", Z = 2.0988, COOR, X = 25.54, Y = _3.07746945 )
POINT( ADD, SHOW, LABE = "w12", Z - -1.27, COOR, X = 2.54, Y - 53.90746945 )
POINT( ADD, SHOW, LABE = "zw12", Z = 1.27, COOR, X = 2.54, Y = 53.90746945 )
POINT( ADD, SHOW, LABE - "w13", Z = -1.27, COOR, X = 0, Y = 53.90746945 )
POINT( ADD, SHOW, LABE = "zw13", Z = 1.27, COOR, X = 0, Y = 53.90746945 )
POINT( ADD, SHOW, LABE = "w14", Z = -1.27, COOR, X = -0.365, Y = 53.54246945 )
POINT( ADD, SHOW, LABE = "zw14", Z = 1.27, COOR, X = -0.365, Y = 53.54246945 )
POINT( ADD, SHOW, LABE = "w15", Z = -1.27, COOR, X = 0, Y = 53.17746945 )
POINT( ADD, SHOW, LABE = "zw15", Z - 1.27, COOR, X = 0, Y = 53.17746945 )
POINT( ADD, SHOW, LABE = "w16", Z = -1.27, COOR, X = 10.07176483,
Y - 52.24418299 )
POINT( ADD, SHOW, LABE = "zw16", Z = 1.27, COOR, X = 10.07176483,
Y = 52.24418299 )
/
//////// first solid /////////////
/
POINT( ADD, LABE = "w101", Z = -1.27, COOR, X = -5.057456634, Y = 56.21364912 )
POINT( ADD, LABE = "zw101", Z = 1.27, COOR, X = -5.057456634, Y = 56.21364912 )
/
POINT( SELE, LABE = "w1" )
POINT( SELE, LABE = "w101" )
POINT( SELE, LABE = "w2" )
CURVE( ADD, ARC, LABE = "cw1" )
/
POINT( SELE, LABE = "zw1" )
  INT( SELE, LABE = "zw101" )
POINT( SELE, LABE = "zw2" )
CURVE( ADD, ARC, LABE = "cwz1" )
/
POINT( SELE, LABE = "w2" )
POINT( SELE, LABE = "w3" )
CURVE( ADD, LINE, LABE = "cw2" )
/
POINT( SELE, LABE = "zw2" )
POINT( SELE, LABE = "zw3" )
CURVE( ADD, LINE, LABE = "cwz2" )
/
POINT( SELE, LABE = "w13" )
POINT( SELE, LABE = "w12" )
CURVE( ADD, SEGM, LABE = "cw9" )
/
POINT( SELE, LABE = "zw13" )
POINT( SELE, LABE = "zw12" )
CURVE( ADD, SEGM, LABE = "cwz9" )
/
POINT( SELE, LABE = "w1" )
POINT( SELE, LABE - "w13" )
CURVE( ADD, LINE, LABE = "cc1" )
/
POINT( SELE, LABE = "zw1" )
 INT( SELE, LABE = "zw13" )
.URVE( ADD, LINE, LABE - "ccz1" )
/
POINT( SELE, LABE - "w3" )
```

```
POINT( SELE, LABE = "w12" )
CURVE( ADD, LINE, LABE = "cc3" )
/
POINT( SELE, LABE = "zw3" )
POINT( SELE, LABE = "zw12" )
C  VE( ADD, LINE, LABE = "ccz3" )
/
POINT( SELE, LABE = "w1" )
POINT( SELE, LABE = "zw1" )
CURVE( ADD, LINE, LABE = "cw11" )
/
POINT( SELE, LABE = "w3" )
POINT( SELE, LABE = "zw3" )
CURVE( ADD, LINE, LABE = "cw12" )
/
POINT( SELE, LABE = "w12" )
POINT( SELE, LABE = "zw12" )
CURVE( ADD, LINE, LABE = "cw13" )
/
POINT( SELE, LABE = "w13" )
POINT( SELE, LABE = "zw13" )
CURVE( ADD, LINE, LABE = "cw14" )
/
//////
/
CURVE( SELE, LABE = "cw1" )
CURVE( SELE, LABE = "cw2" )
CURVE( SELE, LABE = "cc3" )
CURVE( SELE, LABE = "cw9" )
CURVE( SELE, LABE - "cc1" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s1" )
;
CURVE( SELE, LABE = "cwz1" )
CURVE( SELE, LABE = "cwz2" )
CURVE( SELE, LABE = "ccz3" )
CURVE( SELE, LABE = "cwz9" )
CURVE( SELE, LABE = "ccz1" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "sz1" )
/
CURVE( SELE, LABE = "cw1" )
CURVE( SELE, LABE = "cw2" )
CURVE( SELE, LABE - "cw12" )
CURVE( SELE, LABE = "cwz2" )
CURVE( SELE, LABE = "cwz1" )
CURVE( SELE, LABE = "cw11" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 - 2, EDG4 - 1, LABE - "s11" )
/
CURVE( SELE, LABE = "cc3" )
CURVE( SELE, LABE = "cw12" )
CURVE( SELE, LABE = "ccz3" )
CURVE( SELE, LABE - "cw13" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s12" )
/
CURVE( SELE, LABE = "cw9" )
CURVE( SELE, LABE = "cw13" )
CURVE( SELE, LABE = "cwz9" )
  VE( SELE, LABE = "cw14" )
  RFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1, LABE = "s13" )
/
CURVE( SELE, LABE = "cc1" )
```

```
CURVE( SELE, LABE = "cwl4" )
CURVE( SELE, LABE = "ccz1" )
CURVE( SELE, LABE = "cwl1" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s14" )
/
 //////

CURVE( SELE, LABE = "cw1" )
CURVE( SELE, LABE = "cwz1" )
CURVE( SELE, LABE - "cw2" )
CURVE( SELE, LABE = "cwz2" )
MEDGE( ADD, INTE - 6 )
/
CURVE( SELE, LABE = "cw9" )
CURVE( SELE, LABE = "cwz9" )
MEDGE( ADD, INTE = 12 )
/
CURVE( SELE, LABE = "cc1" )
CURVE( SELE, LABE = "ccz1" )
CURVE( SELE, LABE = "cc3" )
CURVE( SELE, LABE - "ccz3" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cwl1" )
CURVE( SELE, LABE = "cwl2" )
CURVE( SELE, LABE = "cwl3" )
CURVE( SELE, LABE = "cwl4" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
////////
/
  RVE( SELE, LABE = "cw1" )
CURVE( SELE, LABE = "cw2" )
CURVE( SELE, LABE = "cc3" )
CURVE( SELE, LABE = "cw9" )
CURVE( SELE, LABE = "cc1" )
MLOOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 - 1, EDG4 - 1, LABE = "ml1" )
/
CURVE( SELE, LABE = "cwz1" )
CURVE( SELE, LABE = "cwz2" )
CURVE( SELE, LABE = "ccz3" )
CURVE( SELE, LABE = "cwz9" )
CURVE( SELE, LABE = "ccz1" )
MLOOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "mlz1" )
/
CURVE( SELE, LABE = "cw1" )
CURVE( SELE, LABE = "cw2" )
CURVE( SELE, LABE = "cwl2" )
CURVE( SELE, LABE = "cwz2" )
CURVE( SELE, LABE = "cwz1" )
CURVE( SELE, LABE = "cwl1" )
MLOOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 - 1, LABE = "ml11" )
/
CURVE( SELE, LABE = "cc3" )
CURVE( SELE, LABE = "cwl2" )
CURVE( SELE, LABE = "ccz3" )
 IRVE( SELE, LABE = "cwl3" )
.LOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1, LABE = "ml12" )
/
CURVE( SELE, LABE = "cw9" )
```

```
CURVE( SELE, LABE = "cw13" )
CURVE( SELE, LABE = "cwz9" )
CURVE( SELE, LABE = "cw14" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml13" )
/
C  VE( SELE, LABE = "cc1" )
C  VE( SELE, LABE = "cw14" )
CURVE( SELE, LABE = "ccz1" )
CURVE( SELE, LABE = "cw11" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml14" )
/
////////
/
SURFACE( SELE, LABE = "s1" )
MLOOP( SELE, LABE = "ml1" )
MFACE( ADD, LABE = "mf1" )
/
SURFACE( SELE, LABE = "sz1" )
MLOOP( SELE, LABE = "mlz1" )
MFACE( ADD, LABE = "mfz1" )
/
SURFACE( SELE, LABE = "s11" )
MLOOP( SELE, LABE = "ml11" )
MFACE( ADD, LABE = "mf11" )
/
SURFACE( SELE, LABE = "s12" )
MLOOP( SELE, LABE = "ml12" )
MFACE( ADD, LABE = "mf12" )
/
SURFACE( SELE, LABE = "s13" )
MLOOP( SELE, LABE = "ml13" )
   CE( ADD, LABE = "mf13" )
/
SURFACE( SELE, LABE = "s14" )
MLOOP( SELE, LABE = "ml14" )
MFACE( ADD, LABE = "mf14" )
/
////////
/
MFACE( SELE, LABE = "mf1" )
MFACE( SELE, LABE = "mfz1" )
MFACE( SELE, LABE = "mf11" )
MFACE( SELE, LABE = "mf12" )
MFACE( SELE, LABE = "mf13" )
MFACE( SELE, LABE = "mf14" )
MSHELL( ADD, VISI, LABE - "mshell1" )
/
//////
/
MSHELL( SELE, LABE = "mshell1" )
MSOLID( ADD, MAP, LABE = "msolid1" )
/
//////// second solid /////////////
/
POINT( SELE, LABE = "w3" )
POINT( SELE, LABE = "w4" )
  VE( ADD, LINE, LABE = "cw3" )
/
POINT( SELE, LABE = "zw3" )
POINT( SELE, LABE = "zw4" )
```

```
CURVE( ADD, LINE, LABE = "cwz3" )
/
POINT( SELE, LABE = "w4" )
POINT( SELE, LABE = "w11" )
CURVE( ADD, LINE, LABE = "cc4" )

 JINT( SELE, LABE = "zw4" )
POINT( SELE, LABE = "zw11" )
CURVE( ADD, LINE, LABE = "ccz4" )
/
POINT( SELE, LABE = "w12" )
POINT( SELE, LABE = "w11" )
CURVE( ADD, LINE, LABE = "cw8" )
/
POINT( SELE, LABE = "zw12" )
POINT( SELE, LABE = "zw11" )
CURVE( ADD, LINE, LABE = "cwz8" )
/
POINT( SELE, LABE = "w4" )
POINT( SELE, LABE = "zw4" )
CURVE( ADD, LINE, LABE = "cw15" )
/
POINT( SELE, LABE = "w11" )
POINT( SELE, LABE = "zw11" )
CURVE( ADD, LINE, LABE = "cw16" )
/
///////
/
CURVE( SELE, LABE = "cw3" )
CURVE( SELE, LABE = "cc4" )
CURVE( SELE, LABE = "cw8" )
  RVE( SELE, LABE = "cc3" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s2" )
/
CURVE( SELE, LABE = "cwz3" )
CURVE( SELE, LABE = "ccz4" )
CURVE( SELE, LABE = "cwz8" )
CURVE( SELE, LABE = "ccz3" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "sz2" )
/
CURVE( SELE, LABE = "cw3" )
CURVE( SELE, LABE = "cw15" )
CURVE( SELE, LABE = "cwz3" )
CURVE( SELE, LABE = "cw12" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s21" )
/
CURVE( SELE, LABE = "cc4" )
CURVE( SELE, LABE = "cw16" )
CURVE( SELE, LABE = "ccz4" )
CURVE( SELE, LABE = "cw15" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s22" )
/
CURVE( SELE, LABE = "cw8" )
CURVE( SELE, LABE = "cw16" )
CURVE( SELE, LABE = "cwz8" )
CURVE( SELE, LABE = "cw13" )
  RFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s23" )

////////
/
```

```
CURVE( SELE, LABE = "cc4" )
CURVE( SELE, LABE = "ccz4" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw3" )
CURVE( SELE, LABE = "cwz3" )
CURVE( SELE, LABE = "cw8" )
CURVE( SELE, LABE = "cwz8" )
MEDGE( ADD, RATI = 1.03, INTE = 32 )
/
CURVE( SELE, LABE = "cw15" )
CURVE( SELE, LABE = "cw16" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
///////
/
CURVE( SELE, LABE = "cw3" )
CURVE( SELE, LABE = "cc4" )
CURVE( SELE, LABE = "cw8" )
CURVE( SELE, LABE = "cc3" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml2" )
/
CURVE( SELE, LABE = "cwz3" )
CURVE( SELE, LABE = "ccz4" )
CURVE( SELE, LABE = "cwz8" )
CURVE( SELE, LABE = "ccz3" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "mlz2" )
/
CURVE( SELE, LABE = "cw3" )
CURVE( SELE, LABE = "cw15" )
CURVE( SELE, LABE = "cwz3" )
CURVE( SELE, LABE = "cw12" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml21" )
/
CURVE( SELE, LABE = "cc4" )
CURVE( SELE, LABE = "cw16" )
CURVE( SELE, LABE = "ccz4" )
CURVE( SELE, LABE = "cw15" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml22" )
/
CURVE( SELE, LABE = "cw8" )
CURVE( SELE, LABE = "cw16" )
CURVE( SELE, LABE = "cwz8" )
CURVE( SELE, LABE = "cw13" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml23" )
/
//////
/
SURFACE( SELE, LABE = "s2" )
MLOOP( SELE, LABE = "ml2" )
MFACE( ADD, LABE = "mf2" )
/
SURFACE( SELE, LABE = "sz2" )
MLOOP( SELE, LABE = "mlz2" )
MFACE( ADD, LABE = "mfz2" )
/
SURFACE( SELE, LABE = "s21" )
MLOOP( SELE, LABE = "ml21" )
MFACE( ADD, LABE = "mf21" )
/
```

```
SURFACE( SELE, LABE = "s22" )
MLOOP( SELE, LABE = "ml22" )
MFACE( ADD, LABE = "mf22" )
/
SURFACE( SELE, LABE = "s23" )
 OOP( SELE, LABE - "ml23" )
 ACE( ADD, LABE = "mf23" )
/
///////
/
MFACE( SELE, LABE = "mf2" )
MFACE( SELE, LABE = "mfz2" )
MFACE( SELE, LABE = "mf21" )
MFACE( SELE, LABE = "mf22" )
MFACE( SELE, LABE = "mf23" )
MFACE( SELE, LABE = "mf12" )
MSHELL( ADD, VISI, LABE = "mshell2" )
/
///////
/
MSHELL( SELE, LABE = "mshell2" )
MSOLID( ADD, MAP, LABE - "msolid2" )
/
//////third solid //////////////////
/
POINT( SELE, LABE = "w4" )
POINT( SELE, LABE = "w5" )
CURVE( ADD, LINE, LABE = "cw4" )
/
POINT( SELE, LABE = "w11" )
POINT( SELE, LABE = "w10" )
 VE( ADD, LINE, LABE = "cw7" )
/
POINT( SELE, LABE - "zw4" )
POINT( SELE, LABE = "zw5" )
CURVE( ADD, LINE, LABE = "cwz4" )
/
POINT( SELE, LABE = "zw11" )
POINT( SELE, LABE = "zw10" )
CURVE( ADD, LINE, LABE = "cwz7" )
/
POINT( SELE, LABE = "w7" )
POINT( SELE, LABE = "zw7" )
CURVE( ADD, LINE, LABE - "cw17" )
/
POINT( SELE, LABE = "w8" )
POINT( SELE, LABE = "zw8" )
CURVE( ADD, LINE, LABE = "cw18" )
/
POINT( SELE, LABE = "w5" )
POINT( SELE, LABE = "w6" )
POINT( SELE, LABE = "w7" )
CURVE( ADD, ARC, LABE = "cw5" )
/
POINT( SELE, LABE = "zw5" )
POINT( SELE, LABE = "zw6" )
 NT( SELE, LABE = "zw7" )
 VE( ADD, ARC, LABE = "cwz5" )
/
POINT( SELE, LABE = "w10" )
```

```
POINT( SELE, LABE = "w9" )
POINT( SELE, LABE = "w8" )
CURVE( ADD, ARC, LABE = "cw6" )
/
POINT( SELE, LABE = "zw10" )
POINT( SELE, LABE = "zw9" )
POINT( SELE, LABE = "zw8" )
CURVE( ADD, ARC, LABE = "cwz6" )
/
POINT( SELE, LABE = "w7" )
POINT( SELE, LABE = "w8" )
CURVE( ADD, LINE, LABE = "co1" )
/
POINT( SELE, LABE = "zw7" )
POINT( SELE, LABE = "zw8" )
CURVE( ADD, LINE, LABE = "coz1" )
/
////////
/
CURVE( SELE, LABE = "cw4" )
CURVE( SELE, LABE = "cw5" )
CURVE( SELE, LABE = "co1" )
CURVE( SELE, LABE = "cw6" )
CURVE( SELE, LABE = "cw7" )
CURVE( SELE, LABE = "cc4" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "s3" )
/
CURVE( SELE, LABE = "cwz4" )
CURVE( SELE, LABE = "cwz5" )
CURVE( SELE, LABE = "coz1" )
CURVE( SELE, LABE = "cwz6" )
CURVE( SELE, LABE = "cwz7" )
CURVE( SELE, LABE = "ccz4" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "sz3" )
/
CURVE( SELE, LABE = "cw4" )
CURVE( SELE, LABE = "cw5" )
CURVE( SELE, LABE = "cw17" )
CURVE( SELE, LABE = "cwz5" )
CURVE( SELE, LABE = "cwz4" )
CURVE( SELE, LABE = "cw15" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "s31" )
/
CURVE( SELE, LABE = "co1" )
CURVE( SELE, LABE = "cw18" )
CURVE( SELE, LABE = "coz1" )
CURVE( SELE, LABE = "cw17" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s32" )
/
CURVE( SELE, LABE = "cw7" )
CURVE( SELE, LABE = "cw6" )
CURVE( SELE, LABE = "cw18" )
CURVE( SELE, LABE = "cwz6" )
CURVE( SELE, LABE = "cwz7" )
CURVE( SELE, LABE = "cw16" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "s33" )

/////
/
CURVE( SELE, LABE = "cw4" )
```

```
CURVE( SELE, LABE = "cw7" )
CURVE( SELE, LABE = "cwz4" )
CURVE( SELE, LABE = "cwz7" )
MEDGE( ADD, INTE = 6 )
/
(  VE( SELE, LABE = "cw5" )
L..VE( SELE, LABE = "cw6" )
CURVE( SELE, LABE = "cwz5" )
CURVE( SELE, LABE = "cwz6" )
MEDGE( ADD, RATI = 1.1, INTE = 10 )
/
CURVE( SELE, LABE = "co1" )
CURVE( SELE, LABE - "coz1" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw17" )
CURVE( SELE, LABE = "cw18" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT - 8, INTE = 10 )
/
////////
/
CURVE( SELE, LABE = "cw4" )
CURVE( SELE, LABE = "cw5" )
CURVE( SELE, LABE = "co1" )
CURVE( SELE, LABE = "cw6" )
CURVE( SELE, LABE = "cw7" )
CURVE( SELE, LABE = "cc4" )
MLOOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "ml3" )
/
CURVE( SELE, LABE = "cwz4" )
CURVE( SELE, LABE = "cwz5" )
   VE( SELE, LABE = "coz1" )
CURVE( SELE, LABE = "cwz6" )
CURVE( SELE, LABE = "cwz7" )
CURVE( SELE, LABE = "ccz4" )
MLOOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "mlz3" )
/
CURVE( SELE, LABE = "cw4" )
CURVE( SELE, LABE = "cw5" )
CURVE( SELE, LABE = "cw17" )
CURVE( SELE, LABE = "cwz5" )
CURVE( SELE, LABE = "cwz4" )
CURVE( SELE, LABE - "cw15" )
MLOOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "ml31" )
/
CURVE( SELE, LABE - "co1" )
CURVE( SELE, LABE = "cw18" )
CURVE( SELE, LABE = "coz1" )
CURVE( SELE, LABE = "cw17" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml32" )
/
CURVE( SELE, LABE = "cw7" )
CURVE( SELE, LABE = "cw6" )
CURVE( SELE, LABE = "cw18" )
CURVE( SELE, LABE = "cwz6" )
CURVE( SELE, LABE = "cwz7" )
  VE( SELE, LABE = "cw16" )
...OOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "ml33" )
/
///////
```

```
/
SURFACE( SELE, LABE = "s3" )
MLOOP( SELE, LABE - "ml3" )
MFACE( ADD, LABE = "mf3" )
/
(  FACE( SELE, LABE = "sz3" )
M__OP( SELE, LABE = "mlz3" )
MFACE( ADD, LABE = "mfz3" )
/
SURFACE( SELE, LABE = "s31" )
MLOOP( SELE, LABE = "ml31" )
MFACE( ADD, LABE = "mf31" )
/
SURFACE( SELE, LABE = "s32" )
MLOOP( SELE, LABE = "ml32" )
MFACE( ADD, LABE = "mf32" )
/
SURFACE( SELE, LABE = "s33" )
MLOOP( SELE, LABE = "ml33" )
MFACE( ADD, LABE = "mf33" )
/
MFACE( SELE, LABE = "mf3" )
MFACE( SELE, LABE = "mfz3" )
MFACE( SELE, LABE = "mf31" )
MFACE( SELE, LABE = "mf32" )
MFACE( SELE, LABE = "mf33" )
MFACE( SELE, LABE = "mf22" )
MSHELL( ADD, VISI, LABE = "mshell3" )
/
///////
/
   ELL( SELE, LABE = "mshell3" )
MSOLID( ADD, MAP, LABE = "msolid3" )
/
/////////fourth solid /////////////
/
POINT( SELE, LABE = "wi3" )
POINT( SELE, LABE = "wi4" )
POINT( SELE, LABE = "wi5" )
CURVE( ADD, ARC, LABE - "cwi0" )
/
POINT( SELE, LABE = "zwi3" )
POINT( SELE, LABE = "zwi4" )
POINT( SELE, LABE = "zwi5" )
CURVE( ADD, ARC, LABE = "cwzi0" )
/
POINT( SELE, LABE = "i2" )
POINT( SELE, LABE = "wi5" )
CURVE( ADD, LINE, LABE = "cc2" )
/
POINT( SELE, LABE = "zi2" )
POINT( SELE, LABE = "zwi5" )
CURVE( ADD, LINE, LABE - "ccz2" )
/
POINT( SELE, LABE = "wi" )
POINT( SELE, LABE = "i2" )
   VE( ADD, LINE, LABE = "ci1" )
/
POINT( SELE, LABE = "zwi" )
POINT( SELE, LABE = "zi2" )
```

```
CURVE( ADD, LINE, LABE = "ciz1" )
/
POINT( SELE, LABE = "w15" )
POINT( SELE, LABE = "zw15" )
CURVE( ADD, LINE, LABE = "cw19" )
/
POINT( SELE, LABE = "i2" )
POINT( SELE, LABE = "zi2" )
CURVE( ADD, LINE, LABE = "cw110" )
/
///////
/
CURVE( SELE, LABE = "cc1" )
CURVE( SELE, LABE = "cw10" )
CURVE( SELE, LABE = "cc2" )
CURVE( SELE, LABE = "ci1" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s4" )
/
CURVE( SELE, LABE = "ccz1" )
CURVE( SELE, LABE = "cwz10" )
CURVE( SELE, LABE = "ccz2" )
CURVE( SELE, LABE = "ciz1" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE - "sz4" )
/
CURVE( SELE, LABE = "cw10" )
CURVE( SELE, LABE = "cw19" )
CURVE( SELE, LABE = "cwz10" )
CURVE( SELE, LABE - "cw14" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 - 1, EDG4 = 1, LABE = "s42" )
/
CURVE( SELE, LABE = "cc2" )
CURVE( SELE, LABE = "cw110" )
CURVE( SELE, LABE = "ccz2" )
CURVE( SELE, LABE = "cw19" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1, LABE = "s43" )
/
CURVE( SELE, LABE = "ci1" )
CURVE( SELE, LABE = "cw110" )
CURVE( SELE, LABE = "ciz1" )
CURVE( SELE, LABE = "cw11" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s44" )
/
/////////
/
CURVE( SELE, LABE = "cc2" )
CURVE( SELE, LABE = "ccz2" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "ci1" )
CURVE( SELE, LABE = "cw10" )
CURVE( SELE, LABE = "ciz1" )
CURVE( SELE, LABE = "cwz10" )
MEDGE( ADD, INTE = 10 )
/
CURVE( SELE, LABE = "cw19" )
CURVE( SELE, LABE = "cw110" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE - 10 )
/
////////
/
```

```
CURVE( SELE, LABE = "cc1" )
CURVE( SELE, LABE = "cw10" )
CURVE( SELE, LABE = "cc2" )
CURVE( SELE, LABE = "ci1" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE - "ml4" )

CURVE( SELE, LABE = "ccz1" )
CURVE( SELE, LABE = "cwz10" )
CURVE( SELE, LABE = "ccz2" )
CURVE( SELE, LABE = "ciz1" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "mlz4" )
/
CURVE( SELE, LABE = "cw10" )
CURVE( SELE, LABE = "cw19" )
CURVE( SELE, LABE = "cwz10" )
CURVE( SELE, LABE = "cw14" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml42" )
/
CURVE( SELE, LABE = "cc2" )
CURVE( SELE, LABE = "cw110" )
CURVE( SELE, LABE = "ccz2" )
CURVE( SELE, LABE = "cw19" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml43" )
/
CURVE( SELE, LABE = "ci1" )
CURVE( SELE, LABE = "cw110" )
CURVE( SELE, LABE = "ciz1" )
CURVE( SELE, LABE = "cw11" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml44" )
/
///////

SURFACE( SELE, LABE = "s4" )
MLOOP( SELE, LABE = "ml4" )
MFACE( ADD, LABE = "mf4" )
/
SURFACE( SELE, LABE = "sz4" )
MLOOP( SELE, LABE - "mlz4" )
MFACE( ADD, LABE = "mfz4" )
/
SURFACE( SELE, LABE = "s42" )
MLOOP( SELE, LABE = "ml42" )
MFACE( ADD, LABE = "mf42" )
/
SURFACE( SELE, LABE = "s43" )
MLOOP( SELE, LABE = "ml43" )
MFACE( ADD, LABE = "mf43" )
/
SURFACE( SELE, LABE = "s44" )
MLOOP( SELE, LABE = "ml44" )
MFACE( ADD, LABE = "mf44" )
/
///////
/
MFACE( SELE, LABE = "mf4" )
MFACE( SELE, LABE = "mfz4" )
MFACE( SELE, LABE = "mf14" )
MFACE( SELE, LABE = "mf42" )
MFACE( SELE, LABE = "mf43" )
MFACE( SELE, LABE = "mf44" )
```

```
MSHELL( ADD, VISI, LABE = "mshell4" )
/
///////
/
MSHELL( SELE, LABE = "mshell4" )
 OLID( ADD, MAP, LABE = "msolid4" )

//////// fifth solid /////////////
/
POINT( SELE, LABE = "w16" )
POINT( SELE, LABE = "i1" )
CURVE( ADD, LINE, LABE = "co2" )
/
POINT( SELE, LABE = "zw16" )
POINT( SELE, LABE = "zi1" )
CURVE( ADD, LINE, LABE = "coz2" )
/
POINT( ADD, NOSH, LABE = "i301", Z = -1.5748, COOR, X = 0, Y = 48.75161568 )
POINT( SELE, LABE = "i2" )
POINT( SELE, LABE = "i301" )
POINT( SELE, LABE = "i1" )
CURVE( ADD, ARC, LABE = "ci2" )
/
POINT( ADD, NOSH, LABE = "zi301", Z = 1.5748, COOR, X = 0, Y = 48.75161568 )
POINT( SELE, LABE = "zi2" )
POINT( SELE, LABE = "zi301" )
POINT( SELE, LABE = "zi1" )
CURVE( ADD, ARC, LABE = "ciz2" )
/
POINT( ADD, NOSH, LABE = "w302", Z = -1.5748, COOR, X = 5.057456634,
Y = 52.94364912 )
 INT( SELE, LABE = "w15" )
POINT( SELE, LABE = "w302" )
POINT( SELE, LABE - "w16" )
CURVE( ADD, ARC, LABE = "cwi1" )
/
POINT( ADD, NOSH, LABE = "zw302", Z = 1.5748, COOR, X - 5.057456634,
Y = 52.94364912 )
POINT( SELE, LABE = "zw15" )
POINT( SELE, LABE = "zw302" )
POINT( SELE, LABE = "zw16" )
CURVE( ADD, ARC, LABE = "cwzi1" )
/
POINT( SELE, LABE = "i1" )
POINT( SELE, LABE = "zi1" )
CURVE( ADD, LINE, LABE = "cwl11" )
/
POINT( SELE, LABE = "w16" )
POINT( SELE, LABE = "zw16" )
CURVE( ADD, LINE, LABE = "cwl12" )
/
///////
/
CURVE( SELE, LABE = "cwi1" )
CURVE( SELE, LABE = "co2" )
CURVE( SELE, LABE = "ci2" )
 JRVE( SELE, LABE = "cc2" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s5" )
/
CURVE( SELE, LABE = "cwzi1" )
```

```
CURVE( SELE, LABE = "coz2" )
CURVE( SELE, LABE = "ciz2" )
CURVE( SELE, LABE = "ccz2" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "sz5" )
/
CURVE( SELE, LABE = "cw11" )
CURVE( SELE, LABE = "cw112" )
CURVE( SELE, LABE = "cwz11" )
CURVE( SELE, LABE = "cw19" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s51" )
/
CURVE( SELE, LABE = "co2" )
CURVE( SELE, LABE = "cw111" )
CURVE( SELE, LABE = "coz2" )
CURVE( SELE, LABE = "cw112" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s52" )
/
CURVE( SELE, LABE = "ci2" )
CURVE( SELE, LABE = "cw111" )
CURVE( SELE, LABE = "ciz2" )
CURVE( SELE, LABE = "cw110" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s53" )
/
///////.
/
CURVE( SELE, LABE = "co2" )
CURVE( SELE, LABE = "coz2" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw11" )
CURVE( SELE, LABE = "ci2" )
CURVE( SELE, LABE = "cwz11" )
CURVE( SELE, LABE = "ciz2" )
MEDGE( ADD, INTE = 12 )
/
CURVE( SELE, LABE = "cw111" )
CURVE( SELE, LABE = "cw112" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
////////
/
CURVE( SELE, LABE = "cw11" )
CURVE( SELE, LABE = "co2" )
CURVE( SELE, LABE = "ci2" )
CURVE( SELE, LABE = "cc2" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml5" )
/
CURVE( SELE, LABE = "cwz11" )
CURVE( SELE, LABE = "coz2" )
CURVE( SELE, LABE = "ciz2" )
CURVE( SELE, LABE = "ccz2" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "mlz5" )
/
CURVE( SELE, LABE = "cw11" )
CURVE( SELE, LABE = "cw112" )
CURVE( SELE, LABE = "cwz11" )
CURVE( SELE, LABE = "cw19" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml51" )
/
CURVE( SELE, LABE = "co2" )
```

```
CURVE( SELE, LABE = "cwl11" )
CURVE( SELE, LABE = "coz2" )
CURVE( SELE, LABE = "cwl12" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml52" )
/
CURVE( SELE, LABE = "ci2" )
CURVE( SELE, LABE = "cwl10" )
CURVE( SELE, LABE = "ciz2" )
CURVE( SELE, LABE = "cwl11" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml53" )
/
///////
/
SURFACE( SELE, LABE = "s5" )
MLOOP( SELE, LABE = "ml5" )
MFACE( ADD, LABE = "mf5" )
/
SURFACE( SELE, LABE = "sz5" )
MLOOP( SELE, LABE = "mlz5" )
MFACE( ADD, LABE = "mfz5" )
/
SURFACE( SELE, LABE = "s51" )
MLOOP( SELE, LABE = "ml51" )
MFACE( ADD, LABE = "mf51" )
/
SURFACE( SELE, LABE = "s52" )
MLOOP( SELE, LABE = "ml52" )
MFACE( ADD, LABE = "mf52" )
/
SURFACE( SELE, LABE = "s53" )
MLOOP( SELE, LABE = "ml53" )
MFACE( ADD, LABE = "mf53" )
/
////////
/
MFACE( SELE, LABE = "mf5" )
MFACE( SELE, LABE = "mfz5" )
MFACE( SELE, LABE = "mf51" )
MFACE( SELE, LABE = "mf52" )
MFACE( SELE, LABE = "mf53" )
MFACE( SELE, LABE = "mf43" )
MSHELL( ADD, VISI, LABE = "mshell5" )
/
//////
/
MSHELL( SELE, LABE = "mshell5" )
MSOLID( ADD, MAP, LABE = "msolid5" )
/
/////// set up entity and mesh ////////////
/
ELEMENT( SETD, BRIC, NODE = 8 )
MSOLID( SELE, LABE = "msolid1" )
MSOLID( SELE, LABE = "msolid2" )
MSOLID( SELE, LABE = "msolid3" )
MSOLID( SELE, LABE = "msolid4" )
MSOLID( SELE, LABE = "msolid5" )
MSOLID( MESH, MAP, ENTI = "fluid" )

END( )
////
```

```
///////////////// boundary group //////////
/////
FI-BC(  )
WINDOW(CHANGE= 1, MATRIX )
   -0.707107   -0.408248    0.577350    0.000000
    0.707107   -0.408248    0.577350    0.000000
    0.000000    0.816497    0.577350    0.000000
    0.000000    0.000000    0.000000    1.000000
   -5.27295    48.91325   -48.16096    -7.52132    15.97957    62.76707
/
///////// setup entity ///////////////
/
BGADD( SELE, ID = 5 )
BGADD( ADD, FACE, ENTI = "outlet" )
BGADD( SELE, ID = 8 )
BGADD( ADD, FACE, ENTI = "inlet" )
BGADD( SELE, ID = 7 )
BGADD( ADD, FACE, ENTI = "per" )
BGADD( SELE, ID = 6 )
BGADD( ADD, FACE, ENTI = "ref" )
BGADD( SELE, ID = 1 )
BGADD( SELE, ID = 2 )
BGADD( SELE, ID = 3 )
BGADD( SELE, ID = 4 )
BGADD( ADD, FACE, ENTI = "wall" )
///
BGADD( SELE, EDGE, ID = 3220 )
BGADD( ADD, EDGE, ENTI = "edger" )
BGADD( SELE, EDGE, ID = 3311 )
BGADD( ADD, EDGE, ENTI = "edgep" )
/
 ID(  )
/
/// create a FIINP file for looking for corner nodes
/
CREATE( FIIN )
/
///////////////// input boundary initial condition and perperties.
/
FIPREP(  )
/
/ simulation control
/
PROBLEM( 3-D, NONL, TURB )
EXECUTION( NEWJ )
SOLUTION( SEGR = 280, ACCF = 0.5, VELC = 0.0001 )
/STRATEGY(SEGREGATED)
/3(u,v)=0.2:1.e-3
/5{5(p,2(u,v=0.2):1.e-2)=0.1:1.e-4}:1.e-4
OPTIONS( UPWI )
PRESSURE( MIXE = 1e-15, CONT )
TURBCONSTANTS(  )
    0,      0,      0,      0,      0,      1
POSTPROCESS(  )
/
/mesh data

 RENUMBER(off)
/
/ material properties
```

```
/
VISCOSITY( K.E., CONS = 5.4212e-06 )
DENSITY( CONS = 1 )
/
/ initial and boundary condition
/
ICNODE( KINE, CONS = 0.005, ALL )
ICNODE( DISS, CONS = 0.001059, ALL )
/
///// per and ref are periodic boundary, but without the corner point.
/
BCPERIODIC( UT1, UN3, ENTI, REFE = "ref", PERI = "per", EXCL, R1NO = 1,
R2NO = 411, P1NO = 465, P2NO = 467 )
/
//// inlet boundary condition, but the corner nodes need redefine.
/
BCNODE( KINE, CONS = 0.005, ENTI = "inlet", INCL )
BCNODE( DISS, CONS = 0.001059, ENTI = "inlet", INCL )
BCNODE( UT1, CONS = -0.9994688, ENTI = "inlet", EXCL )
BCNODE( UT2, CONS = 0, ENTI = "inlet", EXCL )
BCNODE( UN3, CONS = -0.0325893, ENTI = "inlet", EXCL )
/
/ in order to get normal right, BCSYSTEM and BCNODE(COORDINATE)
/ have to be used, then you have define corner node specifically.
/
BCSYSTEM( SET = 1, EDGE, 2TAN )
    0,     0,     0,     0,     0,     0,     0,     0,     1
BCNODE( COOR, ENTI = "inlet" )
/
BCNODE( UN3, CONS = -0.9994688, ENTI = "edger" )
BCNODE( UT1, CONS = 0.0325893, ENTI = "edger" )
BCNODE( UT2, CONS = 0, ENTI = "edger" )
/
BCNODE( UN3, CONS = 0.9994688, ENTI = "edgep" )
BCNODE( UT1, CONS = -0.0325893, ENTI = "edgep" )
BCNODE( UT2, CONS = 0, ENTI = "edgep" )
/
BCNODE( VELO, ZERO, ENTI = "wall" )
/
/ entity properties
/
ENTITY( FLUI, NAME = "fluid" )
/
ENTITY( PLOT, NAME = "outlet" )
/
ENTITY( SLIP, NAME = "per" )
ENTITY( SLIP, NAME = "ref" )
/
ENTITY( SLIP, NAME = "inlet" )
/
ENTITY( WALL, NAME = "wall" )
/
ENTITY( PLOT, NAME = "edger" )
ENTITY( PLOT, NAME = "edgep" )
/
END(  )
/
CREATE( FISO )
RUN( FISO, BACK, FISOLVME = 8000000 )
/ File closed at Thu Dec 21 15:21:06 1995.
```

20%-3% FIDAP INPUT FILE.

```
 File opened for write Wed Jan 31 15:40:08 1996.
/ File opened for write Tue Jan  2 22:44:53 1996.
////// geometry parameters
/
////// grid along mesh edge

/
//// node number for different mesh
/
/
//// boundary condition for input
/
DEVICE( NOGR )
/
////////////// define mesh edge ///////////////
/
///// mesh generation
/
FI-GEN( ELEM = 1, POIN = 1, CURV = 1, SURF = 1, NODE = 0, MEDG = 1, MLOO = 1,
MFAC = 1, BEDG = 1, SPAV = 1, MSHE = 1, MSOL = 1 )
WINDOW(CHANGE= 1, MATRIX )
    1.000000    0.000000    0.000000    0.000000
    0.000000    1.000000    0.000000    0.000000
    0.000000    0.000000    1.000000    0.000000
    0.000000    0.000000    0.000000    1.000000
   -10.00000    10.00000    -7.50000     7.50000    -7.50000     7.50000
WINDOW( CHAN = 1, MATR )
    1,      0,      0,      0
    0,      1,      0,      0
    0,      0,      1,      0
    0,      0,      0,      1
  -10,     10,  -7.5,    7.5,  -7.5,    7.5
/
///// setup key points /////////
/
POINT( ADD, SHOW, LABE = "i1", Z = -1.5748, COOR, X - 8.038459342,
Y = 46.59921454 )
POINT( ADD, SHOW, LABE = "zi1", Z = 1.5748, COOR, X = 8.038459342,
Y = 46.59921454 )
POINT( ADD, SHOW, LABE = "i2", Z = -1.5748, COOR, X = -9.928567926,
Y = 49.51589202 )
POINT( ADD, SHOW, LABE = "zi2", Z = 1.5748, COOR, X = -9.928567926,
Y = 49.51589202 )
POINT( ADD, SHOW, LABE = "w1", Z = -1.27, COOR, X = -10.07176483,
Y = 55.51418299 )
POINT( ADD, SHOW, LABE = "zw1", Z = 1.27, COOR, X = -10.07176483,
Y = 55.51418299 )
POINT( ADD, SHOW, LABE = "w2", Z = -1.27, COOR, X = 0, Y - 56.44746945 )
POINT( ADD, SHOW, LABE = "zw2", Z = 1.27, COOR, X = 0, Y - 56.44746945 )
POINT( ADD, SHOW, LABE = "w3", Z = -1.27, COOR, X = 2.54, Y = 56.44746945 )
POINT( ADD, SHOW, LABE = "zw3", Z = 1.27, COOR, X = 2.54, Y = 56.44746945 )
POINT( ADD, SHOW, LABE = "w4", Z = -2.0988, COOR, X = 25.54, Y = 57.27746945 )
POINT( ADD, SHOW, LABE = "zw4", Z = 2.0988, COOR, X = 25.54, Y = 57.27746945 )
POINT( ADD, SHOW, LABE = "w5", Z = -2.0988, COOR, X = 31.91, Y = 57.27746945 )
POINT( ADD, SHOW, LABE = "zw5", Z = 2.0988, COOR, X = 31.91, Y = 57.27746945 )
POINT( ADD, SHOW, LABE = "w6", Z = -2.0988, COOR, X = 42.87015511,
  = 52.73762456 )
POINT( ADD, SHOW, LABE = "zw6", Z = 2.0988, COOR, X = 42.87015511,
Y = 52.73762456 )
POINT( ADD, SHOW, LABE = "w7", Z = -2.0988, COOR, X = 47.41, Y = 41.77746945 )
```

```
POINT( ADD, SHOW, LABE = "zw7", Z = 2.0988, COOR, X = 47.41, Y = 41.77746945 )
POINT( ADD, SHOW, LABE = "w8", Z = -2.0988, COOR, X = 43.21, Y = 41.77746945 )
POINT( ADD, SHOW, LABE = "zw8", Z = 2.0988, COOR, X = 43.21, Y = 41.77746945 )
POINT( ADD, SHOW, LABE = "w9", Z = -2.0988, COOR, X = 39.90030663,
Y = 49.76777607 )
 OINT( ADD, SHOW, LABE = "zw9", Z = 2.0988, COOR, X = 39.90030663,
Y = 49.76777607 )
POINT( ADD, SHOW, LABE = "w10", Z = -2.0988, COOR, X = 31.91, Y = 53.07746945 )
POINT( ADD, SHOW, LABE = "zw10", Z = 2.0988, COOR, X = 31.91, Y = 53.07746945 )
POINT( ADD, SHOW, LABE = "w11", Z = -2.0988, COOR, X = 25.54, Y = 53.07746945 )
POINT( ADD, SHOW, LABE = "zw11", Z = 2.0988, COOR, X - 25.54, Y = 53.07746945 )
POINT( ADD, SHOW, LABE = "w12", Z = -1.27, COOR, X = 2.54, Y = 53.90746945 )
POINT( ADD, SHOW, LABE = "zw12", Z = 1.27, COOR, X = 2.54, Y = 53.90746945 )
POINT( ADD, SHOW, LABE = "w13", Z = -1.27, COOR, X = 0, Y = 53.90746945 )
POINT( ADD, SHOW, LABE = "zw13", Z = 1.27, COOR, X = 0, Y = 53.90746945 )
POINT( ADD, SHOW, LABE = "w14", Z = -1.27, COOR, X = -0.365, Y = 53.54246945 )
POINT( ADD, SHOW, LABE = "zw14", Z = 1.27, COOR, X = -0.365, Y = 53.54246945 )
POINT( ADD, SHOW, LABE = "w15", Z = -1.27, COOR, X = 0, Y = 53.17746945 )
POINT( ADD, SHOW, LABE = "zw15", Z = 1.27, COOR, X = 0, Y = 53.17746945 )
POINT( ADD, SHOW, LABE = "w16", Z = -1.27, COOR, X = 10.07176483,
Y = 52.24418299 )
POINT( ADD, SHOW, LABE = "zw16", Z = 1.27, COOR, X - 10.07176483,
Y   52.24418299 )
/
//////// Points for suction ////////
/
POINT( ADD, SHOW, LABE = "sp11", Z = 1.27, COOR, X = 1.778, Y = 53.90746945 )
POINT( ADD, SHOW, LABE = "sp12", Z = -1.27, COOR, X = 1.778, Y = 53.90746945 )
POINT( ADD, SHOW, LABE = "sp14", Z = 1.27, COOR, X = 1.778, Y - 56.44746945 )
POINT( ADD, SHOW, LABE = "sp13", Z = -1.27, COOR, X = 1.778, Y - 56.44746945 )
 OINT( ADD, SHOW, LABE = "sp22", Z = -1.27, COOR, X - 1.905, Y = 53.90746945 )
.OINT( ADD, SHOW, LABE = "sp21", Z = 1.27, COOR, X - 1.905, Y = 53.90746945 )
POINT( ADD, SHOW, LABE = "sp23", Z = -1.27, COOR, X = 1.905, Y = 56.44746945 )
POINT( ADD, SHOW, LABE = "sp24", Z = 1.27, COOR, X = 1.905, Y = 56.44746945 )
POINT( ADD, SHOW, LABE = "sp31", Z = 1.27, COOR, X = 2.413, Y = 53.90746945 )
POINT( ADD, SHOW, LABE = "sp32", Z = -1.27, COOR, X = 2.413, Y = 53.90746945 )
POINT( ADD, SHOW, LABE = "sp34", Z = 1.27, COOR, X = 2.413, Y = 56.44746945 )
POINT( ADD, SHOW, LABE = "sp33", Z = -1.27, COOR, X = 2.413, Y = 56.44746945 )
POINT( ADD, SHOW, LABE = "sp41", Z = 1.334069843, COOR, X = 4.318,
Y = 53.84330684 )
POINT( ADD, SHOW, LABE = "sp42", Z = -1.334069843, COOR, X - 4.318,
Y = 53.84330684 )
POINT( ADD, SHOW, LABE = "sp44", Z = 1.334069843, COOR, X - 4.318,
Y - 56.51163206 )
POINT( ADD, SHOW, LABE = "sp43". Z = -1.334069843, COOR, X = 4.318,
Y = 56.51163206 )
POINT( ADD, SHOW, LABE = "sp52", Z = -1.338646261, COOR, X = 4.445,
Y = 53.83872379 )
POINT( ADD, SHOW, LABE = "sp51", Z = 1.338646261, COOR, X = 4.445,
Y = 53.83872379 )
POINT( ADD, SHOW, LABE = "sp53", Z = -1.338646261, COOR, X = 4.445,
Y = 56.5162151 )
POINT( ADD, SHOW, LABE = "sp54", Z = 1.338646261, COOR, X = 4.445,
Y = 56.5162151 )
POINT( ADD, SHOW, LABE = "sp61", Z = 1.379834017, COOR, X = 5.588,
Y = 53.7974764 )
 )INT( ADD, SHOW, LABE = "sp62", Z = -1.379834017, COOR, X = 5.588,
Y = 53.7974764 )
POINT( ADD, SHOW, LABE = "sp64", Z = 1.379834017, COOR, X = 5.588,
Y = 56.55746249 )
```

```
POINT( ADD, SHOW, LABE = "sp63", Z = -1.379834017, COOR, X = 5.588,
Y = 56.55746249 )
POINT( ADD, SHOW, LABE = "sp72", Z = -1.384410435, COOR, X = 5.715,
Y = 53.79289336 )
POINT( ADD, SHOW, LABE = "sp71", Z = 1.384410435, COOR, X = 5.715,
Y = 53.79289336 )
POINT( ADD, SHOW, LABE = "sp73", Z = -1.384410435, COOR, X = 5.715,
Y = 56.56204553 )
POINT( ADD, SHOW, LABE = "sp74", Z = 1.384410435, COOR, X = 5.715,
Y = 56.56204553 )
POINT( ADD, SHOW, LABE = "sp81", Z = 1.425598191, COOR, X = 6.858,
Y = 53.75164597 )
POINT( ADD, SHOW, LABE = "sp82", Z = -1.425598191, COOR, X = 6.858,
Y = 53.75164597 )
POINT( ADD, SHOW, LABE = "sp84", Z = 1.425598191, COOR, X = 6.858,
Y = 56.60329292 )
POINT( ADD, SHOW, LABE = "sp83", Z = -1.425598191, COOR, X = 6.858,
Y = 56.60329292 )
POINT( ADD, SHOW, LABE = "sp92", Z = -1.430174609, COOR, X = 6.985,
Y = 53.74706292 )
POINT( ADD, SHOW, LABE = "sp91", Z = 1.430174609, COOR, X = 6.985,
Y = 53.74706292 )
POINT( ADD, SHOW, LABE = "sp93", Z = -1.430174609, COOR, X = 6.985,
Y = 56.60787597 )
POINT( ADD, SHOW, LABE = "sp94", Z = 1.430174609, COOR, X = 6.985,
Y = 56.60787597 )
POINT( ADD, SHOW, LABE = "sp101", Z = 1.471362365, COOR, X = 8.128,
Y = 53.70581553 )
POINT( ADD, SHOW, LABE = "sp102", Z = -1.471362365, COOR, X = 8.128,
Y = 53.70581553 )
POINT( ADD, SHOW, LABE = "sp104", Z = 1.471362365, COOR, X = 8.128,
Y = 56.64912336 )
POINT( ADD, SHOW, LABE = "sp103", Z = -1.471362365, COOR, X = 8.128,
Y = 56.64912336 )
POINT( ADD, SHOW, LABE = "sp112", Z = -1.475938783, COOR, X = 8.255,
Y = 53.70123249 )
POINT( ADD, SHOW, LABE = "sp111", Z = 1.475938783, COOR, X = 8.255,
Y = 53.70123249 )
POINT( ADD, SHOW, LABE = "sp113", Z = -1.475938783, COOR, X = 8.255,
Y = 56.6537064 )
POINT( ADD, SHOW, LABE = "sp114", Z = 1.475938783, COOR, X = 8.255,
Y = 56.6537064 )
POINT( ADD, SHOW, LABE = "sp121", Z = 1.517126539, COOR, X = 9.398,
Y = 53.6599851 )
POINT( ADD, SHOW, LABE = "sp122", Z = -1.517126539, COOR, X = 9.398,
Y = 53.6599851 )
POINT( ADD, SHOW, LABE = "sp124", Z = 1.517126539, COOR, X = 9.398,
Y = 56.69495379 )
POINT( ADD, SHOW, LABE = "sp123", Z = -1.517126539, COOR, X = 9.398,
Y = 56.69495379 )
POINT( ADD, SHOW, LABE = "sp132", Z = -1.521702957, COOR, X = 9.525,
Y = 53.65540206 )
POINT( ADD, SHOW, LABE = "sp131", Z = 1.521702957, COOR, X = 9.525,
Y = 53.65540206 )
POINT( ADD, SHOW, LABE = "sp133", Z = -1.521702957, COOR, X = 9.525,
Y = 56.69953684 )
POINT( ADD, SHOW, LABE = "sp134", Z = 1.521702957, COOR, X = 9.525,
Y = 56.69953684 )
/
//////// first solid /////////////
```

```
/
POINT( ADD, LABE = "w101", Z = -1.27, COOR, X = -5.057456634, Y = 56.21364912 )
POINT( ADD, LABE = "zw101", Z = 1.27, COOR, X = -5.057456634, Y = 56.21364912 )
/
POINT( SELE, LABE = "w1" )
  INT( SELE, LABE = "w101" )
POINT( SELE, LABE = "w2" )
CURVE( ADD, ARC, LABE = "cw1" )
/
POINT( SELE, LABE = "zw1" )
POINT( SELE, LABE = "zw101" )
POINT( SELE, LABE = "zw2" )
CURVE( ADD, ARC, LABE = "cwz1" )
/
POINT( SELE, LABE = "w2" )
POINT( SELE, LABE = "sp13" )
CURVE( ADD, LINE, LABE = "cw21" )
/
POINT( SELE, LABE = "zw2" )
POINT( SELE, LABE = "sp14" )
CURVE( ADD, LINE, LABE = "cwz21" )
/
POINT( SELE, LABE = "w13" )
POINT( SELE, LABE = "sp12" )
CURVE( ADD, SEGM, LABE   "cw91" )
/
POINT( SELE, LABE = "zw13" )
POINT( SELE, LABE = "sp11" )
CURVE( ADD, SEGM, LABE = "cwz91" )
/
  INT( SELE, LABE = "w1" )
 INT( SELE, LABE = "w13" )
CURVE( ADD, LINE, LABE = "cc1" )
/
POINT( SELE, LABE = "zw1" )
POINT( SELE, LABE = "zw13" )
CURVE( ADD, LINE, LABE = "ccz1" )
/
POINT( SELE, LABE = "w1" )
POINT( SELE, LABE = "zw1" )
CURVE( ADD, LINE, LABE = "cw11" )
/
POINT( SELE, LABE = "w13" )
POINT( SELE, LABE = "zw13" )
CURVE( ADD, LINE, LABE = "cw14" )
/
////// Curve for suction /////////
/
POINT( SELE, LABE = "sp12" )
POINT( SELE, LABE = "sp11" )
CURVE( ADD, LINE, LABE = "csu11" )
/
POINT( SELE, LABE = "sp13" )
POINT( SELE, LABE = "sp12" )
CURVE( ADD, LINE, LABE = "csu12" )
/
  INT( SELE, LABE = "sp13" )
POINT( SELE, LABE = "sp14" )
CURVE( ADD, LINE, LABE = "csu13" )
/
```

```
POINT( SELE, LABE = "sp14" )
POINT( SELE, LABE = "sp11" )
CURVE( ADD, LINE, LABE = "csu14" )
/
////// Surface for first solid ///////

CURVE( SELE, LABE = "cw1" )
CURVE( SELE, LABE = "cw21" )
CURVE( SELE, LABE = "csu12" )
CURVE( SELE, LABE = "cw91" )
CURVE( SELE, LABE = "cc1" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s1" )
/
CURVE( SELE, LABE = "cwz1" )
CURVE( SELE, LABE - "cwz21" )
CURVE( SELE, LABE = "csu14" )
CURVE( SELE, LABE = "cwz91" )
CURVE( SELE, LABE = "ccz1" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "sz1" )
/
CURVE( SELE, LABE = "cw1" )
CURVE( SELE, LABE = "cw21" )
CURVE( SELE, LABE = "csu13" )
CURVE( SELE, LABE = "cwz21" )
CURVE( SELE, LABE = "cwz1" )
CURVE( SELE, LABE = "cw11" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "s11" )
/
CURVE( SELE, LABE = "csu12" )
CURVE( SELE, LABE = "csu11" )
 URVE( SELE, LABE = "csu14" )
 URVE( SELE, LABE = "csu13" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 - 1, EDG3 = 1, EDG4 = 1, LABE = "s12" )
/
CURVE( SELE, LABE = "cw91" )
CURVE( SELE, LABE = "csu11" )
CURVE( SELE, LABE = "cwz91" )
CURVE( SELE, LABE = "cw14" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s13" )
/
CURVE( SELE, LABE = "cc1" )
CURVE( SELE, LABE = "cw14" )
CURVE( SELE, LABE = "ccz1" )
CURVE( SELE, LABE = "cw11" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s14" )
/
///////
/
CURVE( SELE, LABE = "cw1" )
CURVE( SELE, LABE = "cwz1" )
MEDGE( ADD, RATI = 0.8, INTE = 6 )
/
CURVE( SELE, LABE = "cw21" )
CURVE( SELE, LABE = "cwz21" )
MEDGE( ADD, RATI = 0.9, INTE = 6 )
/
 JRVE( SELE, LABE = "cw91" )
CURVE( SELE, LABE = "cwz91" )
MEDGE( ADD, INTE = 12 )
/
```

```
CURVE( SELE, LABE = "cc1" )
CURVE( SELE, LABE = "ccz1" )
CURVE( SELE, LABE = "csu12" )
CURVE( SELE, LABE = "csu14" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )

CURVE( SELE, LABE = "cwl1" )
CURVE( SELE, LABE = "csu13" )
CURVE( SELE, LABE = "csu11" )
CURVE( SELE, LABE = "cwl4" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
////////
/
CURVE( SELE, LABE = "cw1" )
CURVE( SELE, LABE = "cw21" )
CURVE( SELE, LABE = "csu12" )
CURVE( SELE, LABE = "cw91" )
CURVE( SELE, LABE = "cc1" )
MLOOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml1" )
/
CURVE( SELE, LABE = "cwz1" )
CURVE( SELE, LABE = "cwz21" )
CURVE( SELE, LABE = "csu14" )
CURVE( SELE, LABE = "cwz91" )
CURVE( SELE, LABE = "ccz1" )
MLOOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "mlz1" )
/
CURVE( SELE, LABE = "cw1" )
CURVE( SELE, LABE = "cw21" )
CURVE( SELE, LABE = "csu13" )
CURVE( SELE, LABE = "cwz21" )
CURVE( SELE, LABE = "cwz1" )
CURVE( SELE, LABE = "cwl1" )
MLOOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "ml11" )
/
CURVE( SELE, LABE = "csu12" )
CURVE( SELE, LABE = "csu13" )
CURVE( SELE, LABE = "csu14" )
CURVE( SELE, LABE = "csu11" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml12" )
/
CURVE( SELE, LABE = "cw91" )
CURVE( SELE, LABE = "csu11" )
CURVE( SELE, LABE = "cwz91" )
CURVE( SELE, LABE = "cwl4" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml13" )
/
CURVE( SELE, LABE = "cc1" )
CURVE( SELE, LABE - "cwl4" )
CURVE( SELE, LABE = "ccz1" )
CURVE( SELE, LABE = "cwl1" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml14" )
/
////////
/
 JRFACE( SELE, LABE = "s1" )
MLOOP( SELE, LABE = "ml1" )
MFACE( ADD, LABE = "mf1" )
/
```

```
SURFACE( SELE, LABE = "sz1" )
MLOOP( SELE, LABE = "mlz1" )
MFACE( ADD, LABE = "mfz1" )
/
SURFACE( SELE, LABE = "s11" )
 OOP( SELE, LABE = "ml11" )
mFACE( ADD, LABE = "mf11" )
/
SURFACE( SELE, LABE = "s12" )
MLOOP( SELE, LABE = "ml12" )
MFACE( ADD, LABE = "mf12" )
/
SURFACE( SELE, LABE = "s13" )
MLOOP( SELE, LABE = "ml13" )
MFACE( ADD, LABE = "mf13" )
/
SURFACE( SELE, LABE = "s14" )
MLOOP( SELE, LABE = "ml14" )
MFACE( ADD, LABE = "mf14" )
/
////////
/
MFACE( SELE, LABE = "mf1" )
MFACE( SELE, LABE = "mfz1" )
MFACE( SELE, LABE = "mf11" )
MFACE( SELE, LABE - "mf12" )
MFACE( SELE, LABE = "mf13" )
MFACE( SELE, LABE = "mf14" )
MSHELL( ADD, VISI, LABE - "mshell1" )
/
 ////

MSHELL( SELE, LABE = "mshell1" )
MSOLID( ADD, MAP, LABE = "msolid1" )
/
/////
/
/ELEMENT( SETD, BRIC, NODE = 8 )
/
/MSOLID( SELE, LABEL = "msolid1" )
/MSOLID( MESH, MAP, ENTI = "fluid" )
/
///////// Solid for suction ////////
/
//////// first one ///////
/
POINT( SELE, LABE = "sp22" )
POINT( SELE, LABE = "sp21" )
CURVE( ADD, LINE, LABE = "csu21" )
/
POINT( SELE, LABE = "sp23" )
POINT( SELE, LABE = "sp24" )
CURVE( ADD, LINE, LABE = "csu23" )
/
POINT( SELE, LABE = "sp23" )
POINT( SELE, LABE - "sp22" )
 VE( ADD, LINE, LABE = "csu22" )
/
POINT( SELE, LABE = "sp24" )
POINT( SELE, LABE = "sp21" )
```

```
CURVE( ADD, LINE, LABE = "csu24" )
/
POINT( SELE, LABE = "sp11" )
POINT( SELE, LABE = "sp21" )
CURVE( ADD, LINE, LABE - "cwz92" )

POINT( SELE, LABE = "sp12" )
POINT( SELE, LABE = "sp22" )
CURVE( ADD, LINE, LABE = "cw92" )
/
POINT( SELE, LABE = "sp13" )
POINT( SELE, LABE = "sp23" )
CURVE( ADD, LINE, LABE = "cw22" )
/
POINT( SELE, LABE = "sp14" )
POINT( SELE, LABE = "sp24" )
CURVE( ADD, LINE, LABE = "cwz22" )
/
////
/
CURVE( SELE, LABE = "cw22" )
CURVE( SELE, LABE = "csu22" )
CURVE( SELE, LABE = "cw92" )
CURVE( SELE, LABE = "csu12" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE - "ssu11" )
/
CURVE( SELE, LABE = "cwz22" )
CURVE( SELE, LABE = "csu24" )
CURVE( SELE, LABE = "cwz92" )
CURVE( SELE, LABE = "csu14" )
'URFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu12" )

CURVE( SELE, LABE = "cw22" )
CURVE( SELE, LABE = "csu23" )
CURVE( SELE, LABE = "cwz22" )
CURVE( SELE, LABE = "csu13" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 - 1, EDG3 = 1, EDG4 - 1, LABE = "ssu13" )
/
CURVE( SELE, LABE = "csu22" )
CURVE( SELE, LABE = "csu23" )
CURVE( SELE, LABE = "csu24" )
CURVE( SELE, LABE = "csu21" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu14" )
/
CURVE( SELE, LABE = "cw92" )
CURVE( SELE, LABE = "csu21" )
CURVE( SELE, LABE = "cwz92" )
CURVE( SELE, LABE = "csu11" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu15" )
/
//////
/
CURVE( SELE, LABE = "csu22" )
CURVE( SELE, LABE = "csu24" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE - 10 )
/
 JRVE( SELE, LABE = "cw22" )
CURVE( SELE, LABE = "cwz22" )
CURVE( SELE, LABE = "cw92" )
CURVE( SELE, LABE = "cwz92" )
```

```
MEDGE( ADD, INTE = 2 )
/
CURVE( SELE, LABE = "csu21" )
CURVE( SELE, LABE = "csu23" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )

CURVE( SELE, LABE = "cw22" )
CURVE( SELE, LABE = "csu22" )
CURVE( SELE, LABE = "cw92" )
CURVE( SELE, LABE = "csu12" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu11" )
/
CURVE( SELE, LABE = "cwz22" )
CURVE( SELE, LABE = "csu24" )
CURVE( SELE, LABE = "cwz92" )
CURVE( SELE, LABE = "csu14" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu12" )
/
CURVE( SELE, LABE = "cw22" )
CURVE( SELE, LABE = "csu23" )
CURVE( SELE, LABE = "cwz22" )
CURVE( SELE, LABE = "csu13" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu13" )
/
CURVE( SELE, LABE = "csu22" )
CURVE( SELE, LABE = "csu23" )
CURVE( SELE, LABE = "csu24" )
CURVE( SELE, LABE = "csu21" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu14" )
/
CURVE( SELE, LABE = "cw92" )
CURVE( SELE, LABE = "csu21" )
CURVE( SELE, LABE = "cwz92" )
CURVE( SELE, LABE = "csu11" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu15" )
/
SURFACE( SELE, LABE = "ssu11" )
MLOOP( SELE, LABE = "mlsu11" )
MFACE( ADD, LABE = "mfsu11" )
/
SURFACE( SELE, LABE = "ssu12" )
MLOOP( SELE, LABE = "mlsu12" )
MFACE( ADD, LABE = "mfsu12" )
/
SURFACE( SELE, LABE = "ssu13" )
MLOOP( SELE, LABE = "mlsu13" )
MFACE( ADD, LABE = "mfsu13" )
/
SURFACE( SELE, LABE = "ssu14" )
MLOOP( SELE, LABE = "mlsu14" )
MFACE( ADD, LABE = "mfsu14" )

SURFACE( SELE, LABE = "ssu15" )
MLOOP( SELE, LABE = "mlsu15" )
MFACE( ADD, LABE = "mfsu15" )
```

```
/
MFACE( SELE, LABE = "mfsui1" )
MFACE( SELE, LABE = "mfsui2" )
MFACE( SELE, LABE = "mfsui3" )
MFACE( SELE, LABE = "mfsui4" )
 ACE( SELE, LABE = "mfsui5" )
MFACE( SELE, LABE = "mf12" )
MSHELL( ADD, VISI, LABE = "mshellsui" )
/
//////
/
MSHELL( SELE, LABE = "mshellsui" )
MSOLID( ADD, MAP, LABE = "msolidsui" )
/
/////////second one ///////
/
POINT( SELE, LABE = "sp32" )
POINT( SELE, LABE = "sp31" )
CURVE( ADD, LINE, LABE = "csu31" )
/
POINT( SELE, LABE = "sp33" )
POINT( SELE, LABE = "sp34" )
CURVE( ADD, LINE, LABE = "csu33" )
/
POINT( SELE, LABE = "sp33" )
POINT( SELE, LABE = "sp32" )
CURVE( ADD, LINE, LABE = "csu32" )
/
POINT( SELE, LABE = "sp34" )
POINT( SELE, LABE = "sp31" )
 RVE( ADD, LINE, LABE = "csu34" )

POINT( SELE, LABE = "sp21" )
POINT( SELE, LABE = "sp31" )
CURVE( ADD, LINE, LABE = "cwz93" )
/
POINT( SELE, LABE = "sp22" )
POINT( SELE, LABE = "sp32" )
CURVE( ADD, LINE, LABE = "cw93" )
/
POINT( SELE, LABE = "sp23" )
POINT( SELE, LABE = "sp33" )
CURVE( ADD, LINE, LABE = "cw23" )
/
POINT( SELE, LABE = "sp24" )
POINT( SELE, LABE = "sp34" )
CURVE( ADD, LINE, LABE = "cwz23" )
/
////
/
CURVE( SELE, LABE = "cw23" )
CURVE( SELE, LABE = "csu32" )
CURVE( SELE, LABE = "cw93" )
CURVE( SELE, LABE = "csu22" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu21" )
/
 RVE( SELE, LABE = "cwz23" )
CURVE( SELE, LABE = "csu34" )
CURVE( SELE, LABE = "cwz93" )
CURVE( SELE, LABE = "csu24" )
```

```
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1, LABE = "ssu22" )
/
CURVE( SELE, LABE = "cw23" )
CURVE( SELE, LABE = "csu33" )
CURVE( SELE, LABE = "cwz23" )
CURVE( SELE, LABE = "csu23" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu23" )
/
CURVE( SELE, LABE = "csu32" )
CURVE( SELE, LABE = "csu33" )
CURVE( SELE, LABE = "csu34" )
CURVE( SELE, LABE = "csu31" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu24" )
/
CURVE( SELE, LABE = "cw93" )
CURVE( SELE, LABE = "csu31" )
CURVE( SELE, LABE = "cwz93" )
CURVE( SELE, LABE = "csu21" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu25" )
/
/////
/
CURVE( SELE, LABE = "csu32" )
CURVE( SELE, LABE = "csu34" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw23" )
CURVE( SELE, LABE - "cwz23" )
CURVE( SELE, LABE = "cw93" )
CURVE( SELE, LABE = "cwz93" )
MEDGE( ADD, INTE = 3 )
/
CURVE( SELE, LABE = "csu31" )
CURVE( SELE, LABE = "csu33" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
/////
/
CURVE( SELE, LABE = "cw23" )
CURVE( SELE, LABE = "csu32" )
CURVE( SELE, LABE = "cw93" )
CURVE( SELE, LABE = "csu22" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE - "mlsu21" )
/
CURVE( SELE, LABE = "cwz23" )
CURVE( SELE, LABE = "csu34" )
CURVE( SELE, LABE = "cwz93" )
CURVE( SELE, LABE = "csu24" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1,
LABE = "mlsu22" )
/
CURVE( SELE, LABE = "cw23" )
CURVE( SELE, LABE = "csu33" )
CURVE( SELE, LABE = "cwz23" )
CURVE( SELE, LABE = "csu23" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1,
LABE = "mlsu23" )
/
CURVE( SELE, LABE = "csu32" )
```

```
CURVE( SELE, LABE = "csu33" )
CURVE( SELE, LABE = "csu34" )
CURVE( SELE, LABE = "csu31" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 - 1, EDG4 = 1,
LABE = "mlsu24" )

CURVE( SELE, LABE = "cw93" )
CURVE( SELE, LABE = "csu31" )
CURVE( SELE, LABE = "cwz93" )
CURVE( SELE, LABE = "csu21" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu25" )
/
SURFACE( SELE, LABE = "ssu21" )
MLOOP( SELE, LABE = "mlsu21" )
MFACE( ADD, LABE = "mfsu21" )
/
SURFACE( SELE, LABE = "ssu22" )
MLOOP( SELE, LABE = "mlsu22" )
MFACE( ADD, LABE = "mfsu22" )
/
SURFACE( SELE, LABE = "ssu23" )
MLOOP( SELE, LABE = "mlsu23" )
MFACE( ADD, LABE = "mfsu23" )
/
SURFACE( SELE, LABE = "ssu24" )
MLOOP( SELE, LABE = "mlsu24" )
MFACE( ADD, LABE = "mfsu24" )
/
SURFACE( SELE, LABE = "ssu25" )
MLOOP( SELE, LABE = "mlsu25" )
MFACE( ADD, LABE - "mfsu25" )
/
////
/
MFACE( SELE, LABE = "mfsu21" )
MFACE( SELE, LABE = "mfsu22" )
MFACE( SELE, LABE = "mfsu23" )
MFACE( SELE, LABE = "mfsu24" )
MFACE( SELE, LABE = "mfsu25" )
MFACE( SELE, LABE = "mfsu14" )
MSHELL( ADD, VISI, LABE = "mshellsu2" )
/
//////
/
MSHELL( SELE, LABE = "mshellsu2" )
MSOLID( ADD, MAP, LABE = "msolidsu2" )
/
//////// third one ///////
/
POINT( SELE, LABE = "sp33" )
POINT( SELE, LABE = "w3" )
CURVE( ADD, LINE, LABE = "cw24" )
/
POINT( SELE, LABE = "sp34" )
POINT( SELE, LABE = "zw3" )
CURVE( ADD, LINE, LABE = "cwz24" )
/
POINT( SELE, LABE = "sp32" )
POINT( SELE, LABE = "w12" )
```

```
CURVE( ADD, SEGM, LABE = "cw94" )
/
POINT( SELE, LABE = "sp31" )
POINT( SELE, LABE = "zw12" )
CURVE( ADD, SEGM, LABE = "cwz94" )
/
POINT( SELE, LABE = "w3" )
POINT( SELE, LABE = "w12" )
CURVE( ADD, LINE, LABE = "cc3" )
/
POINT( SELE, LABE - "zw3" )
POINT( SELE, LABE = "zw12" )
CURVE( ADD, LINE, LABE = "ccz3" )
/
POINT( SELE, LABE = "w3" )
POINT( SELE, LABE = "zw3" )
CURVE( ADD, LINE, LABE = "cw12" )
/
POINT( SELE, LABE = "w12" )
POINT( SELE, LABE = "zw12" )
CURVE( ADD, LINE, LABE - "cw13" )
/
/////
/
CURVD( SELE, LABE = "cw24" )
CURVE( SELE, LABE = "cc3" )
CURVE( SELE, LABE - "cw94" )
CURVE( SELE, LABE = "csu32" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1, LABE   "ssu31" )
/
  RVE( SELE, LABE = "cwz24" )
  RVE( SELE, LABE = "ccz3" )
CURVE( SELE, LABE = "cwz94" )
CURVE( SELE, LABE = "csu34" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3   1, EDG4 = 1, LABE = "ssu32" )
/
CURVD( SELE, LABE = "cw24" )
CURVE( SELE, LABE = "cw12" )
CURVE( SELE, LABE = "cwz24" )
CURVE( SELE, LABE = "csu33" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu33" )
/
CURVE( SELE, LABE = "cc3" )
CURVE( SELE, LABE = "cw12" )
CURVE( SELE, LABE = "ccz3" )
CURVE( SELE, LABE = "cw13" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 - 1, EDG4 = 1, LABE = "ssu34" )
/
CURVE( SELE, LABE = "cw94" )
CURVE( SELE, LABE = "cw13" )
CURVE( SELE, LABE = "cwz94" )
CURVE( SELE, LABE = "csu31" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu35" )
/
//////
/
  VE( SELE, LABE = "cw24" )
CURVE( SELE, LABE = "cwz24" )
CURVE( SELE, LABE = "cw94" )
CURVE( SELE, LABE = "cwz94" )
```

```
MEDGE( ADD, INTE = 2 )
/
CURVE( SELE, LABE = "cc3" )
CURVE( SELE, LABE = "ccz3" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )

CURVE( SELE, LABE = "cw12" )
CURVE( SELE, LABE = "cw13" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
//////
/
CURVE( SELE, LABE = "cw24" )
CURVE( SELE, LABE = "cc3" )
CURVE( SELE, LABE = "cw94" )
CURVE( SELE, LABE = "csu32" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu31" )
/
CURVE( SELE, LABE = "cwz24" )
CURVE( SELE, LABE = "ccz3" )
CURVE( SELE, LABE = "cwz94" )
CURVE( SELE, LABE = "csu34" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu32" )
/
CURVE( SELE, LABE = "cw24" )
CURVE( SELE, LABE = "cw12" )
CURVE( SELE, LABE = "cwz24" )
CURVE( SELE, LABE = "csu33" )
 LOOP( ADD, MAP, VISI, EDG1 = 1, EDG2   1, EDG3 = 1, EDG4 = 1,
 ABE = "mlsu33" )
/
CURVE( SELE, LABE = "cc3" )
CURVE( SELE, LABE - "cw12" )
CURVE( SELE, LABE = "ccz3" )
CURVE( SELE, LABE = "cw13" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu34" )
/
CURVE( SELE, LABE = "cw94" )
CURVE( SELE, LABE = "cw13" )
CURVE( SELE, LABE = "cwz94" )
CURVE( SELE, LABE = "csu31" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu35" )
/
/////
/
SURFACE( SELE, LABE = "ssu31" )
MLOOP( SELE, LABE = "mlsu31" )
MFACE( ADD, LABE = "mfsu31" )
/
SURFACE( SELE, LABE = "ssu32" )
MLOOP( SELE, LABE = "mlsu32" )
MFACE( ADD, LABE = "mfsu32" )

SURFACE( SELE, LABE = "ssu33" )
MLOOP( SELE, LABE = "mlsu33" )
MFACE( ADD, LABE - "mfsu33" )
```

```
/
SURFACE( SELE, LABE = "ssu34" )
MLOOP( SELE, LABE = "mlsu34" )
MFACE( ADD, LABE = "mfsu34" )
/
(  :FACE( SELE, LABE = "ssu35" )
MLOOP( SELE, LABE = "mlsu35" )
MFACE( ADD, LABE = "mfsu35" )
/
////
/
MFACE( SELE, LABE = "mfsu31" )
MFACE( SELE, LABE = "mfsu32" )
MFACE( SELE, LABE = "mfsu33" )
MFACE( SELE, LABE = "mfsu34" )
MFACE( SELE, LABE = "mfsu35" )
MFACE( SELE, LABE = "mfsu24" )
MSHELL( ADD, VISI, LABE = "mshellsu3" )
/
//////
/
MSHELL( SELE, LABE = "mshellsu3" )
MSOLID( ADD, MAP, LABE = "msolidsu3" )
/
//////// second solid /////////////
/
////// solid for suction /////
/
//////third one ///
/
  NT( SELE, LABE = "sp42" )
..INT( SELE, LABE = "sp41" )
CURVE( ADD, LINE, LABE - "csu41" )
/
POINT( SELE, LABE = "sp43" )
POINT( SELE, LABE = "sp44" )
CURVE( ADD, LINE, LABE = "csu43" )
/
POINT( SELE, LABE = "sp43" )
POINT( SELE, LABE = "sp42" )
CURVE( ADD, LINE, LABE = "csu42" )
/
POINT( SELE, LABE = "sp44" )
POINT( SELE, LABE = "sp41" )
CURVE( ADD, LINE, LABE = "csu44" )
/
POINT( SELE, LABE = "w3" )
POINT( SELE, LABE = "sp43" )
CURVE( ADD, LINE, LABE = "cw31" )
/
POINT( SELE, LABE = "zw3" )
POINT( SELE, LABE = "sp44" )
CURVE( ADD, LINE, LABE = "cwz31" )
/
POINT( SELE, LABE = "w12" )
POINT( SELE, LABE = "sp42" )
  VE( ADD, LINE, LABE = "cw81" )
/
POINT( SELE, LABE = "zw12" )
POINT( SELE, LABE = "sp41" )
```

```
CURVE( ADD, LINE, LABE = "cwz81" )
/
/////
/
CURVE( SELE, LABE = "cw31" )
CURVE( SELE, LABE = "csu42" )
CURVE( SELE, LABE = "cw81" )
CURVE( SELE, LABE = "cc3" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu41" )
/
CURVE( SELE, LABE = "cwz31" )
CURVE( SELE, LABE = "csu44" )
CURVE( SELE, LABE = "cwz81" )
CURVE( SELE, LABE = "ccz3" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu42" )
/
CURVE( SELE, LABE = "cw31" )
CURVE( SELE, LABE = "csu43" )
CURVE( SELE, LABE = "cwz31" )
CURVE( SELE, LABE = "cw12" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu43" )
/
CURVE( SELE, LABE = "csu42" )
CURVE( SELE, LABE = "csu43" )
CURVE( SELE, LABE = "csu44" )
CURVE( SELE, LABE = "csu41" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu44" )
/
CURVE( SELE, LABE = "cw81" )
CURVE( SELE, LABE = "csu41" )
CURVE( SELE, LABE = "cwz81" )
CURVE( SELE, LABE = "cw13" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu45" )
/
//////
/
CURVE( SELE, LABE = "csu42" )
CURVE( SELE, LABE = "csu44" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw81" )
CURVE( SELE, LABE = "cwz81" )
CURVE( SELE, LABE = "cw31" )
CURVE( SELE, LABE = "cwz31" )
MEDGE( ADD, INTE = 6 )
/
CURVE( SELE, LABE = "csu41" )
CURVE( SELE, LABE = "csu43" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
//////
/
CURVE( SELE, LABE = "cw31" )
CURVE( SELE, LABE = "csu42" )
CURVE( SELE, LABE - "cw81" )
CURVE( SELE, LABE = "cc3" )
LOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu41" )
/
CURVE( SELE, LABE = "cwz31" )
```

```
CURVE( SELE, LABE = "csu44" )
CURVE( SELE, LABE = "cwz81" )
CURVE( SELE, LABE = "ccz3" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu42" )
/
CURVE( SELE, LABE = "cw31" )
CURVE( SELE, LABE = "csu43" )
CURVE( SELE, LABE = "cwz31" )
CURVE( SELE, LABE = "cw12" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu43" )
/
CURVE( SELE, LABE = "csu42" )
CURVE( SELE, LABE = "csu43" )
CURVE( SELE, LABE = "csu44" )
CURVE( SELE, LABE = "csu41" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu44" )
/
CURVE( SELE, LABE = "cw81" )
CURVE( SELE, LABE = "csu41" )
CURVE( SELE, LABE = "cwz81" )
CURVE( SELE, LABE = "cw13" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu45" )
/
////////
/
SURFACE( SELE, LABE = "ssu41" )
  OOP( SELE, LABE = "mlsu41" )
...ACE( ADD, LABE = "mfsu41" )
/
SURFACE( SELE, LABE = "ssu42" )
MLOOP( SELE, LABE = "mlsu42" )
MFACE( ADD, LABE = "mfsu42" )
/
SURFACE( SELE, LABE = "ssu43" )
MLOOP( SELE, LABE = "mlsu43" )
MFACE( ADD, LABE = "mfsu43" )
/
SURFACE( SELE, LABE = "ssu44" )
MLOOP( SELE, LABE = "mlsu44" )
MFACE( ADD, LABE = "mfsu44" )
/
SURFACE( SELE, LABE = "ssu45" )
MLOOP( SELE, LABE = "mlsu45" )
MFACE( ADD, LABE = "mfsu45" )
/
////
/
MFACE( SELE, LABE = "mfsu41" )
MFACE( SELE, LABE = "mfsu42" )
MFACE( SELE, LABE = "mfsu43" )
MFACE( SELE, LABE = "mfsu44" )
MFACE( SELE, LABE = "mfsu45" )
  ACE( SELE, LABE = "mfsu34" )
MSHELL( ADD, VISI, LABE = "mshellsu4" )
/
//////
```

```
/
MSHELL( SELE, LABE = "mshellsu4" )
MSOLID( ADD, MAP, LABE = "msolidsu4" )
/
/
/,,//// Secon one //////
/
POINT( SELE, LABE = "sp43" )
POINT( SELE, LABE = "sp53" )
CURVE( ADD, LINE, LABE = "cw32" )
/
POINT( SELE, LABE = "sp44" )
POINT( SELE, LABE = "sp54" )
CURVE( ADD, LINE, LABE = "cwz32" )
/
POINT( SELE, LABE = "sp42" )
POINT( SELE, LABE = "sp52" )
CURVE( ADD, SEGM, LABE = "cw82" )
/
POINT( SELE, LABE = "sp41" )
POINT( SELE, LABE = "sp51" )
CURVE( ADD, SEGM, LABE = "cwz82" )
/
POINT( SELE, LABE = "sp52" )
POINT( SELE, LABE = "sp51" )
CURVE( ADD, LINE, LABE = "csu51" )
/
POINT( SELE, LABE = "sp53" )
POINT( SELE, LABE = "sp52" )
CURVE( ADD, LINE, LABE = "csu52" )
.
.OINT( SELE, LABE = "sp53" )
POINT( SELE, LABE - "sp54" )
CURVE( ADD, LINE, LABE = "csu53" )
/
POINT( SELE, LABE = "sp54" )
POINT( SELE, LABE = "sp51" )
CURVE( ADD, LINE, LABE = "csu54" )
/
////////
/
CURVE( SELE, LABE = "cw32" )
CURVE( SELE, LABE = "csu52" )
CURVE( SELE, LABE = "cw82" )
CURVE( SELE, LABE = "csu42" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu51" )
/
CURVE( SELE, LABE = "cwz32" )
CURVE( SELE, LABE = "csu54" )
CURVE( SELE, LABE = "cwz82" )
CURVE( SELE, LABE = "csu44" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu52" )
/
CURVE( SELE, LABE = "csu52" )
CURVE( SELE, LABE = "csu53" )
CURVE( SELE, LABE = "csu54" )
 JRVE( SELE, LABE = "csu51" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu54" )
/
CURVE( SELE, LABE = "cw32" )
```

```
CURVE( SELE, LABE = "csu53" )
CURVE( SELE, LABE = "cwz32" )
CURVE( SELE, LABE = "csu43" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE - "ssu53" )
/
( RVE( SELE, L^BE = "cw82" )
CURVE( SELE, LABE = "csu51" )
CURVE( SELE, LABE = "cwz82" )
CURVE( SELE, LABE = "csu41" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu55" )
/
///////
/
CURVE( SELE, LABE = "csu52" )
CURVE( SELE, LABE = "csu54" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw32" )
CURVE( SELE, LABE = "cwz32" )
CURVE( SELE, LABE = "cw82" )
CURVE( SELE, LABE = "cwz82" )
MEDGE( ADD, INTE = 2 )
/
CURVE( SELE, LABE = "csu51" )
CURVE( SELE, LABE = "csu53" )
MEDGE( ADD, LSTF, RATI - 8, 2RAT = 8, INTE = 10 )
/
////////
/
CURVE( SELE, LABE = "cw32" )
( RVE( SELE, LABE = "csu52" )
CURVE( SELE, LABE = "cw82" )
CURVE( SELE, LABE = "csu42" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu51" )
/
CURVE( SELE, LABE = "cwz32" )
CURVE( SELE, LABE - "csu54" )
CURVE( SELE, LABE = "cwz82" )
CURVE( SELE, LABE = "csu44" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu52" )
/
CURVE( SELE, LABE = "cw32" )
CURVE( SELE, LABE = "csu53" )
CURVE( SELE, LABE = "cwz32" )
CURVE( SELE, LABE = "csu43" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu53" )
/
CURVE( SELE, LABE = "csu52" )
CURVE( SELE, LABE = "csu53" )
CURVE( SELE, LABE = "csu54" )
CURVE( SELE, LABE = "csu51" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu54" )

CURVE( SELE, LABE = "cw82" )
CURVE( SELE, LABE = "csu51" )
CURVE( SELE, LABE = "cwz82" )
```

```
CURVE( SELE, LABE = "csu41" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu55" )
/
////////

SURFACE( SELE, LABE = "ssu51" )
MLOOP( SELE, LABE = "mlsu51" )
MFACE( ADD, LABE = "mfsu51" )
/
SURFACE( SELE, LABE = "ssu52" )
MLOOP( SELE, LABE = "mlsu52" )
MFACE( ADD, LABE = "mfsu52" )
/
SURFACE( SELE, LABE = "ssu53" )
MLOOP( SELE, LABE = "mlsu53" )
MFACE( ADD, LABE = "mfsu53" )
/
SURFACE( SELE, LABE = "ssu54" )
MLOOP( SELE, LABE = "mlsu54" )
MFACE( ADD, LABE = "mfsu54" )
/
SURFACE( SELE, LABE = "ssu55" )
MLOOP( SELE, LABE = "mlsu55" )
MFACE( ADD, LABE = "mfsu55" )
/
////////
/
MFACE( SELE, LABE = "mfsu51" )
MFACE( SELE, LABE = "mfsu52" )
 FACE( SELE, LABE = "mfsu53" )
MFACE( SELE, LABE = "mfsu54" )
MFACE( SELE, LABE = "mfsu55" )
MFACE( SELE, LABE = "mfsu44" )
MSHELL( ADD, VISI, LABE = "mshellsu5" )
/
//////
/
MSHELL( SELE, LABE = "mshellsu5" )
MSOLID( ADD, MAP, LABE = "msolidsu5" )
/
//////// second one /////////////
/
POINT( SELE, LABE = "sp53" )
POINT( SELE, LABE = "sp63" )
CURVE( ADD, LINE, LABE = "cw33" )
/
POINT( SELE, LABE = "sp54" )
POINT( SELE, LABE = "sp64" )
CURVE( ADD, LINE, LABE = "cwz33" )
/
POINT( SELE, LABE = "sp52" )
POINT( SELE, LABE = "sp62" )
CURVE( ADD, LINE, LABE = "cw83" )
/
POINT( SELE, LABE = "sp51" )
 OINT( SELE, LABE = "sp61" )
CURVE( ADD, LINE, LABE = "cwz83" )
/
POINT( SELE, LABE = "sp63" )
```

```
POINT( SELE, LABE = "sp62" )
CURVE( ADD, LINE, LABE = "csu62" )
/
POINT( SELE, LABE = "sp62" )
POINT( SELE, LABE = "sp61" )
CURVE( ADD, LINE, LABE = "csu61" )
/
POINT( SELE, LABE = "sp64" )
POINT( SELE, LABE = "sp61" )
CURVE( ADD, LINE, LABE = "csu64" )
/
POINT( SELE, LABE = "sp63" )
POINT( SELE, LABE - "sp64" )
CURVE( ADD, LINE, LABE = "csu63" )
/
///////
/
CURVE( SELE, LABE = "cw33" )
CURVE( SELE, LABE = "csu62" )
CURVE( SELE, LABE = "cw83" )
CURVE( SELE, LABE = "csu52" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1, LABE = "ssu61" )
/
CURVE( SELE, LABE = "cwz33" )
CURVE( SELE, LABE = "csu64" )
CURVE( SELE, LABE = "cwz83" )
CURVE( SELE, LABE = "csu54" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu62" )
/
CURVE( SELE, LABE = "cw33" )
CURVE( SELE, LABE = "csu63" )
CURVE( SELE, LABE = "cwz33" )
CURVE( SELE, LABE = "csu53" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu63" )
/
CURVE( SELE, LABE = "csu62" )
CURVE( SELE, LABE = "csu63" )
CURVE( SELE, LABE - "csu64" )
CURVE( SELE, LABE = "csu61" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu64" )
/
CURVE( SELE, LABE = "cw83" )
CURVE( SELE, LABE = "csu61" )
CURVE( SELE, LABE = "cwz83" )
CURVE( SELE, LABE = "csu51" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu65" )
/
////////
/
CURVE( SELE, LABE = "csu62" )
CURVE( SELE, LABE = "csu64" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "csu61" )
CURVE( SELE, LABE = "csu63" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )

CURVE( SELE, LABE - "cw33" )
CURVE( SELE, LABE = "cwz33" )
CURVE( SELE, LABE = "cw83" )
```

```
CURVE( SELE, LABE = "cwz83" )
MEDGE( ADD, INTE = 4 )
/
///////
/
CURVE( SELE, LABE = "cw33" )
CURVE( SELE, LABE = "csu62" )
CURVE( SELE, LABE = "cw83" )
CURVE( SELE, LABE = "csu52" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu61" )
/
CURVE( SELE, LABE = "cwz33" )
CURVE( SELE, LABE = "csu64" )
CURVE( SELE, LABE = "cwz83" )
CURVE( SELE, LABE = "csu54" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu62" )
/
CURVE( SELE, LABE = "cw33" )
CURVE( SELE, LABE = "csu63" )
CURVE( SELE, LABE = "cwz33" )
CURVE( SELE, LABE = "csu53" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu63" )
/
CURVE( SELE, LABE = "csu62" )
CURVE( SELE, LABE = "csu63" )
CURVE( SELE, LABE = "csu64" )
CURVE( SELE, LABE = "csu61" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu64" )
/
CURVE( SELE, LABE = "cw83" )
CURVE( SELE, LABE = "csu61" )
CURVE( SELE, LABE = "cwz83" )
CURVE( SELE, LABE = "csu51" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu65" )
/
//////
/
SURFACE( SELE, LABE = "ssu61" )
MLOOP( SELE, LABE = "mlsu61" )
MFACE( ADD, LABE = "mfsu61" )
/
SURFACE( SELE, LABE = "ssu62" )
MLOOP( SELE, LABE = "mlsu62" )
MFACE( ADD, LABE = "mfsu62" )
/
SURFACE( SELE, LABE = "ssu63" )
MLOOP( SELE, LABE = "mlsu63" )
MFACE( ADD, LABE = "mfsu63" )
/
SURFACE( SELE, LABE = "ssu64" )
MLOOP( SELE, LABE = "mlsu64" )
MFACE( ADD, LABE = "mfsu64" )
/
SURFACE( SELE, LABE = "ssu65" )
MLOOP( SELE, LABE = "mlsu65" )
```

```
MFACE( ADD, LABE = "mfsu65" )
/
///////
/
MFACE( SELE, LABE = "mfsu61" )
( 'ACE( SELE, LABE = "mfsu62" )
mFACE( SELE, LABE = "mfsu63" )
MFACE( SELE, LABE = "mfsu64" )
MFACE( SELE, LABE = "mfsu65" )
MFACE( SELE, LABE = "mfsu54" )
MSHELL( ADD, VISI, LABE = "mshellsu6" )
/
///////
/
MSHELL( SELE, LABE = "mshellsu6" )
MSOLID( ADD, MAP, LABE = "msolidsu6" )
/
//////third one/////////////////
/
POINT( SELE, LABE = "sp63" )
POINT( SELE, LABE = "sp73" )
CURVE( ADD, LINE, LABE = "cw34" )
/
POINT( SELE, LABE = "sp64" )
POINT( SELE, LABE = "sp74" )
CURVE( ADD, LINE, LABE = "cwz34" )
/
POINT( SELE, LABE = "sp62" )
POINT( SELE, LABE = "sp72" )
CURVE( ADD, LINE, LABE = "cw84" )

.JINT( SELE, LABE = "sp61" )
POINT( SELE, LABE = "sp71" )
CURVE( ADD, LINE, LABE = "cwz84" )
/
POINT( SELE, LABE = "sp73" )
POINT( SELE, LABE = "sp72" )
CURVE( ADD, LINE, LABE = "csu72" )
/
POINT( SELE, LABE = "sp72" )
POINT( SELE, LABE = "sp71" )
CURVE( ADD, LINE, LABE = "csu71" )
/
POINT( SELE, LABE = "sp74" )
POINT( SELE, LABE = "sp71" )
CURVE( ADD, LINE, LABE = "csu74" )
/
POINT( SELE, LABE = "sp73" )
POINT( SELE, LABE = "sp74" )
CURVE( ADD, LINE, LABE = "csu73" )
/
////////
/
CURVE( SELE, LABE = "cw34" )
CURVE( SELE, LABE = "csu72" )
CURVE( SELE, LABE = "cw84" )
( RVE( SELE, LABE = "csu62" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu71" )
/
CURVE( SELE, LABE = "cwz34" )
```

```
CURVE( SELE, LABE = "csu74" )
CURVE( SELE, LABE = "cwz84" )
CURVE( SELE, LABE = "csu64" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu72" )
/
 JRVE( SELE, LABE = "cw34" )
CURVE( SELE, LABE = "csu73" )
CURVE( SELE, LABE = "cwz34" )
CURVE( SELE, LABE = "csu63" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu73" )
/
CURVE( SELE, LABE = "csu72" )
CURVE( SELE, LABE = "csu73" )
CURVE( SELE, LABE = "csu74" )
CURVE( SELE, LABE = "csu71" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu74" )
/
CURVE( SELE, LABE = "cw84" )
CURVE( SELE, LABE = "csu71" )
CURVE( SELE, LABE = "cwz84" )
CURVE( SELE, LABE = "csu61" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu75" )
/
///////
/
CURVE( SELE, LABE = "csu72" )
CURVE( SELE, LABE = "csu74" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw34" )
 URVE( SELE, LABE = "cwz34" )
 URVE( SELE, LABE = "cw84" )
CURVE( SELE, LABE = "cwz84" )
MEDGE( ADD, INTE = 2 )
/
CURVE( SELE, LABE = "csu71" )
CURVE( SELE, LABE - "csu73" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
////////
/
CURVE( SELE, LABE = "cw34" )
CURVE( SELE, LABE = "csu72" )
CURVE( SELE, LABE = "cw84" )
CURVE( SELE, LABE = "csu62" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu71" )
/
CURVE( SELE, LABE = "cwz34" )
CURVE( SELE, LABE = "csu74" )
CURVE( SELE, LABE = "cwz84" )
CURVE( SELE, LABE = "csu64" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu72" )
/
CURVE( SELE, LABE = "cw34" )
 JRVE( SELE, LABE = "csu73" )
CURVE( SELE, LABE = "cwz34" )
CURVE( SELE, LABE = "csu63" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
```

```
LABE = "mlsu73" )
/
CURVE( SELE, LABE = "csu72" )
CURVE( SELE, LABE = "csu73" )
CURVE( SELE, LABE = "csu74" )
CURVE( SELE, LABE = "csu71" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu74" )
/
CURVE( SELE, LABE = "cw84" )
CURVE( SELE, LABE = "csu71" )
CURVE( SELE, LABE = "cwz84" )
CURVE( SELE, LABE = "csu61" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu75" )
/
///////
/
SURFACE( SELE, LABE = "ssu71" )
MLOOP( SELE, LABE = "mlsu71" )
MFACE( ADD, LABE = "mfsu71" )
/
SURFACE( SELE, LABE = "ssu72" )
MLOOP( SELE, LABE = "mlsu72" )
MFACE( ADD, LABE = "mfsu72" )
/
SURFACE( SELE, LABE = "ssu73" )
MLOOP( SELE, LABE = "mlsu73" )
MFACE( ADD, LABE = "mfsu73" )
/
SURFACE( SELE, LABE = "ssu74" )
MLOOP( SELE, LABE = "mlsu74" )
MFACE( ADD, LABE = "mfsu74" )
/
SURFACE( SELE, LABE = "ssu75" )
MLOOP( SELE, LABE = "mlsu75" )
MFACE( ADD, LABE = "mfsu75" )
/
MFACE( SELE, LABE = "mfsu71" )
MFACE( SELE, LABE = "mfsu72" )
MFACE( SELE, LABE = "mfsu73" )
MFACE( SELE, LABE = "mfsu74" )
MFACE( SELE, LABE = "mfsu75" )
MFACE( SELE, LABE = "mfsu64" )
MSHELL( ADD, VISI, LABE = "mshellsu7" )
/
///////
/
MSHELL( SELE, LABE = "mshellsu7" )
MSOLID( ADD, MAP, LABE = "msolidsu7" )
/
/////////fourth one //////////////
/
POINT( SELE, LABE = "sp73" )
POINT( SELE, LABE = "sp83" )
CURVE( ADD, LINE, LABE = "cw35" )

POINT( SELE, LABE = "sp74" )
POINT( SELE, LABE = "sp84" )
CURVE( ADD, LINE, LABE = "cwz35" )
```

```
/
POINT( SELE, LABE = "sp72" )
POINT( SELE, LABE = "sp82" )
CURVE( ADD, LINE, LABE = "cw85" )
/
 OINT( SELE, LABE = "sp71" )
POINT( SELE, LABE = "sp81" )
CURVE( ADD, LINE, LABE = "cwz85" )
/
POINT( SELE, LABE = "sp83" )
POINT( SELE, LABE = "sp82" )
CURVE( ADD, LINE, LABE = "csu82" )
/
POINT( SELE, LABE = "sp84" )
POINT( SELE, LABE = "sp81" )
CURVE( ADD, LINE, LABE = "csu84" )
/
POINT( SELE, LABE = "sp83" )
POINT( SELE, LABE = "sp84" )
CURVE( ADD, LINE, LABE = "csu83" )
/
POINT( SELE, LABE = "sp82" )
POINT( SELE, LABE = "sp81" )
CURVE( ADD, LINE, LABE = "csu81" )
/
///////
/
CURVE( SELE, LABE = "cw35" )
CURVE( SELE, LABE = "csu82" )
CURVE( SELE, LABE = "cw85" )
 URVE( SELE, LABE = "csu72" )
 URFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu81" )
/
CURVE( SELE, LABE = "cwz35" )
CURVE( SELE, LABE = "csu84" )
CURVE( SELE, LABE = "cwz85" )
CURVE( SELE, LABE = "csu74" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1, LABE = "ssu82" )
/
CURVE( SELE, LABE = "cw35" )
CURVE( SELE, LABE = "csu83" )
CURVE( SELE, LABE = "cwz35" )
CURVE( SELE, LABE = "csu73" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1, LABE = "ssu83" )
/
CURVE( SELE, LABE = "csu82" )
CURVE( SELE, LABE = "csu83" )
CURVE( SELE, LABE = "csu84" )
CURVE( SELE, LABE = "csu81" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu84" )
/
CURVE( SELE, LABE = "cw85" )
CURVE( SELE, LABE = "csu81" )
CURVE( SELE, LABE = "cwz85" )
CURVE( SELE, LABE = "csu71" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE - "ssu85" )

/////////
/
CURVE( SELE, LABE = "csu82" )
```

```
CURVE( SELE, LABE = "csu84" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "csu81" )
CURVE( SELE, LABE = "csu83" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw35" )
CURVE( SELE, LABE = "cwz35" )
CURVE( SELE, LABE = "cw85" )
CURVE( SELE, LABE = "cwz85" )
MEDGE( ADD, INTE = 4 )
/
////////
/
CURVE( SELE, LABE = "cw35" )
CURVE( SELE, LABE = "csu82" )
CURVE( SELE, LABE = "cw85" )
CURVE( SELE, LABE = "csu72" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu81" )
/
CURVE( SELE, LABE = "cwz35" )
CURVE( SELE, LABE = "csu84" )
CURVE( SELE, LABE = "cwz85" )
CURVE( SELE, LABE = "csu74" )
MLOOP( ADD, MAP, VISI, EDG1 - 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu82" )
/
CURVE( SELE, LABE = "cw35" )
CURVE( SELE, LABE = "csu83" )
CURVE( SELE, LABE = "cwz35" )
CURVE( SELE, LABE = "csu73" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 - 1, EDG4 - 1,
LABE = "mlsu83" )
/
CURVE( SELE, LABE = "csu82" )
CURVE( SELE, LABE = "csu83" )
CURVE( SELE, LABE = "csu84" )
CURVE( SELE, LABE = "csu81" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu84" )
/
CURVE( SELE, LABE = "cw85" )
CURVE( SELE, LABE = "csu81" )
CURVE( SELE, LABE = "cwz85" )
CURVE( SELE, LABE = "csu71" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu85" )
/
///////
/
SURFACE( SELE, LABE = "ssu81" )
MLOOP( SELE, LABE = "mlsu81" )
MFACE( ADD, LABE = "mfsu81" )
/
SURFACE( SELE, LABE = "ssu82" )
MLOOP( SELE, LABE = "mlsu82" )
MFACE( ADD, LABE = "mfsu82" )
/
```

```
SURFACE( SELE, LABE = "ssu83" )
MLOOP( SELE, LABE = "mlsu83" )
MFACE( ADD, LABE = "mfsu83" )
/
SURFACE( SELE, LABE = "ssu84" )
MLOOP( SELE, LABE = "mlsu84" )
MFACE( ADD, LABE = "mfsu84" )
/
SURFACE( SELE, LABE = "ssu85" )
MLOOP( SELE, LABE = "mlsu85" )
MFACE( ADD, LABE = "mfsu85" )
/
///////
/
MFACE( SELE, LABE = "mfsu81" )
MFACE( SELE, LABE = "mfsu82" )
MFACE( SELE, LABE = "mfsu83" )
MFACE( SELE, LABE = "mfsu84" )
MFACE( SELE, LABE = "mfsu85" )
MFACE( SELE, LABE = "mfsu74" )
MSHELL( ADD, VISI, LABE = "mshellsu8" )
/
///////
/
MSHELL( SELE, LABE = "mshellsu8" )
MSOLID( ADD, MAP, LABE = "msolidsu8" )
/
//////// fifth one /////////////
/
POINT( SELE, LABE = "sp83" )
POINT( SELE, LABE = "sp93" )
CURVE( ADD, LINE, LABE = "cw36" )
/
POINT( SELE, LABE = "sp84" )
POINT( SELE, LABE = "sp94" )
CURVE( ADD, LINE, LABE = "cwz36" )
/
POINT( SELE, LABE = "sp82" )
POINT( SELE, LABE = "sp92" )
CURVE( ADD, LINE, LABE = "cw86" )
/
POINT( SELE, LABE = "sp81" )
POINT( SELE, LABE = "sp91" )
CURVE( ADD, LINE, LABE = "cwz86" )
/
POINT( SELE, LABE = "sp93" )
POINT( SELE, LABE = "sp92" )
CURVE( ADD, LINE, LABE = "csu92" )
/
POINT( SELE, LABE = "sp92" )
POINT( SELE, LABE = "sp91" )
CURVE( ADD, LINE, LABE = "csu91" )
/
POINT( SELE, LABE = "sp93" )
POINT( SELE, LABE = "sp94" )
CURVE( ADD, LINE, LABE = "csu93" )

POINT( SELE, LABE = "sp94" )
POINT( SELE, LABE = "sp91" )
CURVE( ADD, LINE, LABE = "csu94" )
```

```
/
///////
/
CURVE( SELE, LABE = "cw36" )
CURVE( SELE, LABE = "csu92" )
{  IRVE( SELE, !  BE = "cw86" )
CURVE( SELE, LABE = "csu82" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu91" )
/
CURVE( SELE, LABE = "cwz36" )
CURVE( SELE, LABE = "csu94" )
CURVE( SELE, LABE = "cwz86" )
CURVE( SELE, LABE = "csu84" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu92" )
/
CURVE( SELE, LABE = "cw36" )
CURVE( SELE, LABE = "csu93" )
CURVE( SELE, LABE = "cwz36" )
CURVE( SELE, LABE = "csu83" )
SURFACE( ADD, WIRE, EDG1 - 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu93" )
/
CURVE( SELE, LABE = "csu92" )
CURVE( SELE, LABE = "csu93" )
CURVE( SELE, LABE = "csu94" )
CURVE( SELE, LABE = "csu91" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4   1, LABE = "ssu94" )
/
CURVE( SELE, LABE = "cw86" )
CURVE( SELE, LABE = "csu91" )
CURVE( SELE, LABE = "cwz86" )
  'RVE( SELE, LABE = "csu81" )
.JURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1, LABE = "ssu95" )
/
///////
/
CURVE( SELE, LABE = "csu92" )
CURVE( SELE, LABE = "csu94" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw36" )
CURVE( SELE, LABE = "cwz36" )
CURVE( SELE, LABE = "cwz86" )
CURVE( SELE, LABE = "cw86" )
MEDGE( ADD, INTE = 2 )
/
CURVE( SELE, LABE = "csu91" )
CURVE( SELE, LABE = "csu93" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
////////
/
CURVE( SELE, LABE = "cw36" )
CURVE( SELE, LABE = "csu92" )
CURVE( SELE, LABE = "cw86" )
CURVE( SELE, LABE = "csu82" )
MLOOP( ADD, MAP, VISI, EDG1 - 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
  BE = "mlsu91" )
/
CURVE( SELE, LABE = "cwz36" )
CURVE( SELE, LABE = "csu94" )
```

```
CURVE( SELE, LABE = "cwz86" )
CURVE( SELE, LABE = "csu84" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu92" )
/
CURVE( SELE, LABE = "cw36" )
CURVE( SELE, LABE = "csu95" )
CURVE( SELE, LABE = "cwz36" )
CURVE( SELE, LABE = "csu83" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu93" )
/
CURVE( SELE, LABE = "csu92" )
CURVE( SELE, LABE = "csu93" )
CURVE( SELE, LABE = "csu94" )
CURVE( SELE, LABE = "csu91" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu94" )
/
CURVE( SELE, LABE = "cw86" )
CURVE( SELE, LABE = "csu91" )
CURVE( SELE, LABE = "cwz86" )
CURVE( SELE, LABE = "csu81" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu95" )
/
///////
/
SURFACE( SELE, LABE = "ssu91" )
MLOOP( SELE, LABE = "mlsu91" )
MFACE( ADD, LABE = "mfsu91" )

SURFACE( SELE, LABE = "ssu92" )
MLOOP( SELE, LABE = "mlsu92" )
MFACE( ADD, LABE = "mfsu92" )
/
SURFACE( SELE, LABE = "ssu93" )
MLOOP( SELE, LABE = "mlsu93" )
MFACE( ADD, LABE = "mfsu93" )
/
SURFACE( SELE, LABE = "ssu94" )
MLOOP( SELE, LABE = "mlsu94" )
MFACE( ADD, LABE = "mfsu94" )
/
SURFACE( SELE, LABE = "ssu95" )
MLOOP( SELE, LABE = "mlsu95" )
MFACE( ADD, LABE = "mfsu95" )
/
////////
/
MFACE( SELE, LABE = "mfsu91" )
MFACE( SELE, LABE = "mfsu92" )
MFACE( SELE, LABE = "mfsu93" )
MFACE( SELE, LABE = "mfsu94" )
MFACE( SELE, LABE = "mfsu95" )
MFACE( SELE, LABE = "mfsu84" )
MSHELL( ADD, VISI, LABE = "mshellsu9" )
/
//////
/
```

```
MSHELL( SELE, LABE = "mshellsu9" )
MSOLID( ADD, MAP, LABE = "msolidsu9" )
/
/////// sixth one ///////
/
  INT( SELE, LABE = "sp93" )
POINT( SELE, LABE = "sp103" )
CURVE( ADD, LINE, LABE = "cw37" )
/
POINT( SELE, LABE = "sp94" )
POINT( SELE, LABE = "sp104" )
CURVE( ADD, LINE, LABE = "cwz37" )
/
POINT( SELE, LABE = "sp92" )
POINT( SELE, LABE = "sp102" )
CURVE( ADD, LINE, LABE = "cw87" )
/
POINT( SELE, LABE = "sp91" )
POINT( SELE, LABE = "sp101" )
CURVE( ADD, LINE, LABE = "cwz87" )
/
POINT( SELE, LABE = "sp103" )
POINT( SELE, LABE - "sp102" )
CURVE( ADD, LINE, LABE = "csu102" )
/
POINT( SELE, LABE = "sp102" )
POINT( SELE, LABE = "sp101" )
CURVE( ADD, LINE, LABE = "csu101" )
/
POINT( SELE, LABE = "sp103" )
  INT( SELE, LABE = "sp104" )
 URVE( ADD, LINE, LABE = "csu103" )
/
POINT( SELE, LABE = "sp104" )
POINT( SELE, LABE = "sp101" )
CURVE( ADD, LINE, LABE - "csu104" )
/
///////
/
CURVE( SELE, LABE = "cw37" )
CURVE( SELE, LABE = "csu102" )
CURVE( SELE, LABE = "cw87" )
CURVE( SELE, LABE = "csu92" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu101" )
/
CURVE( SELE, LABE = "cwz37" )
CURVE( SELE, LABE = "csu104" )
CURVE( SELE, LABE = "cwz87" )
CURVE( SELE, LABE = "csu94" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu102" )
/
CURVE( SELE, LABE = "cw37" )
CURVE( SELE, LABE = "csu103" )
CURVE( SELE, LABE = "cwz37" )
CURVE( SELE, LABE = "csu93" )
SURFACE( ADD, WIRE, EDG1 - 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu103" )

CURVE( SELE, LABE = "csu102" )
CURVE( SELE, LABE = "csu103" )
CURVE( SELE, LABE = "csu104" )
```

```
CURVE( SELE, LABE = "csu101" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu104" )
/
CURVE( SELE, LABE = "cw87" )
CURVE( SELE, LABE = "csu101" )
( RVE( SELE, LABE = "cwz87" )
CURVE( SELE, LABE = "csu91" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu105" )
/
///////
/
CURVE( SELE, LABE = "csu102" )
CURVE( SELE, LABE = "csu104" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw37" )
CURVE( SELE, LABE = "cwz37" )
CURVE( SELE, LABE = "cwz87" )
CURVE( SELE, LABE = "cw87" )
MEDGE( ADD, INTE = 4 )
/
CURVE( SELE, LABE = "csu101" )
CURVE( SELE, LABE = "csu103" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
////////
/
CURVE( SELE, LABE = "cw37" )
CURVE( SELE, LABE = "csu102" )
CURVE( SELE, LABE = "cw87" )
 'RVE( SELE, LABE = "csu92" )
.LOOP( ADD, MAP, VISI, EDG1 - 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu101" )
/
CURVE( SELE, LABE = "cwz37" )
CURVE( SELE, LABE = "csu104" )
CURVE( SELE, LABE = "cwz87" )
CURVE( SELE, LABE = "csu94" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu102" )
/
CURVE( SELE, LABE = "cw37" )
CURVE( SELE, LABE = "csu103" )
CURVE( SELE, LABE = "cwz37" )
CURVE( SELE, LABE = "csu93" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu103" )
/
CURVE( SELE, LABE = "csu102" )
CURVE( SELE, LABE = "csu103" )
CURVE( SELE, LABE = "csu104" )
CURVE( SELE, LABE = "csu101" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu104" )
/
CURVE( SELE, LABE = "cw87" )
( RVE( SELE, LABE = "csu101" )
CURVE( SELE, LABE = "cwz87" )
CURVE( SELE, LABE = "csu91" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1,
```

```
LABE = "mlsu105" )
/
///////
/
SURFACE( SELE, LABE = "ssu101" )
  OOP( SELE, LABE = "mlsu101" )
mFACE( ADD, LABE = "mfsu101" )
/
SURFACE( SELE, LABE = "ssu102" )
MLOOP( SELE, LABE = "mlsu102" )
MFACE( ADD, LABE = "mfsu102" )
/
SURFACE( SELE, LABE = "ssu103" )
MLOOP( SELE, LABE = "mlsu103" )
MFACE( ADD, LABE = "mfsu103" )
/
SURFACE( SELE, LABE = "ssu104" )
MLOOP( SELE, LABE = "mlsu104" )
MFACE( ADD, LABE = "mfsu104" )
/
SURFACE( SELE, LABE = "ssu105" )
MLOOP( SELE, LABE = "mlsu105" )
MFACE( ADD, LABE = "mfsu105" )
/
////////
/
MFACE( SELE, LABE = "mfsu101" )
MFACE( SELE, LABE = "mfsu102" )
MFACE( SELE, LABE = "mfsu103" )
MFACE( SELE, LABE = "mfsu104" )
  ACE( SELE, LABE = "mfsu105" )
..ACE( SELE, LABE = "mfsu94" )
MSHELL( ADD, VISI, LABE = "mshellsu10" )
/
//////
/
MSHELL( SELE, LABE = "mshellsu10" )
MSOLID( ADD, MAP, LABE = "msolidsu10" )
/
////// seventh one //////
/
POINT( SELE, LABE = "sp103" )
POINT( SELE, LABE = "sp113" )
CURVE( ADD, LINE, LABE = "cw38" )
/
POINT( SELE, LABE = "sp104" )
POINT( SELE, LABE = "sp114" )
CURVE( ADD, LINE, LABE = "cwz38" )
/
POINT( SELE, LABE - "sp102" )
POINT( SELE, LABE = "sp112" )
CURVE( ADD, LINE, LABE = "cw88" )
/
POINT( SELE, LABE = "sp101" )
POINT( SELE, LABE = "sp111" )
CURVE( ADD, LINE, LABE = "cwz88" )

POINT( SELE, LABE = "sp113" )
POINT( SELE, LABE = "sp112" )
CURVE( ADD, LINE, LABE = "csu112" )
```

```
/
POINT( SELE, LABE = "sp112" )
POINT( SELE, LABE = "sp111" )
CURVE( ADD, LINE, LABE = "csu111" )
/
POINT( SELE, LABE = "sp113" )
POINT( SELE, LABE = "sp114" )
CURVE( ADD, LINE, LABE = "csu113" )
/
POINT( SELE, LABE = "sp114" )
POINT( SELE, LABE = "sp111" )
CURVE( ADD, LINE, LABE = "csu114" )
/
///////
/
CURVE( SELE, LABE = "cw38" )
CURVE( SELE, LABE = "csu112" )
CURVE( SELE, LABE = "cw88" )
CURVE( SELE, LABE = "csu102" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu111" )
/
CURVE( SELE, LABE = "cwz38" )
CURVE( SELE, LABE = "csu114" )
CURVE( SELE, LABE = "cwz88" )
CURVE( SELE, LABE = "csu104" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu112" )
/
CURVE( SELE, LABE = "cw38" )
CURVE( SELE, LABE = "csu113" )
CURVE( SELE, LABE = "cwz38" )
CURVE( SELE, LABE = "csu103" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu113" )
/
CURVE( SELE, LABE = "csu112" )
CURVE( SELE, LABE = "csu113" )
CURVE( SELE, LABE = "csu114" )
CURVE( SELE, LABE = "csu111" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu114" )
/
CURVE( SELE, LABE = "cw88" )
CURVE( SELE, LABE = "csu111" )
CURVE( SELE, LABE = "cwz88" )
CURVE( SELE, LABE = "csu101" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ssu115" )
/
///////
/
CURVE( SELE, LABE = "csu112" )
CURVE( SELE, LABE = "csu114" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw38" )
CURVE( SELE, LABE = "cwz38" )
CURVE( SELE, LABE = "cwz88" )
CURVE( SELE, LABE = "cw88" )
MEDGE( ADD, INTE = 2 )

CURVE( SELE, LABE = "csu111" )
CURVE( SELE, LABE = "csu113" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
```

```
/
////////
/
CURVE( SELE, LABE = "cw38" )
CURVE( SELE, LABE = "csu112" )
CURVE( SELE, LABE = "cw88" )
CURVE( SELE, LABE = "csu102" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu111" )
/
CURVE( SELE, LABE = "cwz38" )
CURVE( SELE, LABE = "csu114" )
CURVE( SELE, LABE = "cwz88" )
CURVE( SELE, LABE = "csu104" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu112" )
/
CURVE( SELE, LABE = "cw38" )
CURVE( SELE, LABE = "csu113" )
CURVE( SELE, LABE = "cwz38" )
CURVE( SELE, LABE = "csu103" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu113" )
/
CURVE( SELE, LABE = "csu112" )
CURVE( SELE, LABE = "csu113" )
CURVE( SELE, LABE = "csu114" )
CURVE( SELE, LABE = "csu111" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu114" )

CURVE( SELE, LABE = "cw88" )
CURVE( SELE, LABE = "csu111" )
CURVE( SELE, LABE = "cwz88" )
CURVE( SELE, LABE = "csu101" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1,
LABE = "mlsu115" )
/
///////
/
SURFACE( SELE, LABE = "ssu111" )
MLOOP( SELE, LABE = "mlsu111" )
MFACE( ADD, LABE = "mfsu111" )
/
SURFACE( SELE, LABE = "ssu112" )
MLOOP( SELE, LABE = "mlsu112" )
MFACE( ADD, LABE = "mfsu112" )
/
SURFACE( SELE, LABE = "ssu113" )
MLOOP( SELE, LABE = "mlsu113" )
MFACE( ADD, LABE = "mfsu113" )
/
SURFACE( SELE, LABE = "ssu114" )
MLOOP( SELE, LABE = "mlsu114" )
MFACE( ADD, LABE = "mfsu114" )
/
SURFACE( SELE, LABE = "ssu115" )
MLOOP( SELE, LABE = "mlsu115" )
MFACE( ADD, LABE = "mfsu115" )
/
```

```
////////
/
MFACE( SELE, LABE = "mfsu111" )
MFACE( SELE, LABE = "mfsu112" )
MFACE( SELE, LABE = "mfsu113" )
(  CE( SELE, LABE = "mfsu114" )
MFACE( SELE, LABE = "mfsu115" )
MFACE( SELE, LABE = "mfsu104" )
MSHELL( ADD, VISI, LABE = "mshellsu11" )
/
//////
/
MSHELL( SELE, LABE = "mshellsu11" )
MSOLID( ADD, MAP, LABE = "msolidsu11" )
/
///// second face //////
/
POINT( SELE, LABE = "sp113" )
POINT( SELE, LABE = "w4" )
CURVE( ADD, LINE, LABE = "cw3" )
/
POINT( SELE, LABE = "sp114" )
POINT( SELE, LABE = "zw4" )
CURVE( ADD, LINE, LABE = "cwz3" )
/
POINT( SELE, LABE = "w4" )
POINT( SELE, LABE = "w11" )
CURVE( ADD, LINE, LABE = "cc4" )
/
POINT( SELE, LABE = "zw4" )
!  NT( SELE, LABE = "zw11" )
CURVE( ADD, LINE, LABE = "ccz4" )
/
POINT( SELE, LABE = "sp112" )
POINT( SELE, LABE = "w11" )
CURVE( ADD, LINE, LABE = "cw8" )
/
POINT( SELE, LABE = "sp111" )
POINT( SELE, LABE = "zw11" )
CURVE( ADD, LINE, LABE = "cwz8" )
/
POINT( SELE, LABE - "w4" )
POINT( SELE, LABE = "zw4" )
CURVE( ADD, LINE, LABE = "cw15" )
/
POINT( SELE, LABE = "w11" )
POINT( SELE, LABE = "zw11" )
CURVE( ADD, LINE, LABE = "cw16" )
/
///////
/
CURVE( SELE, LABE = "cw3" )
CURVE( SELE, LABE = "cc4" )
CURVE( SELE, LABE = "cw8" )
CURVE( SELE, LABE = "csu112" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s2" )
(
CURVE( SELE, LABE = "cwz3" )
CURVE( SELE, LABE = "ccz4" )
CURVE( SELE, LABE = "cwz8" )
```

```
CURVE( SELE, LABE = "csu114" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "sz2" )
/
CURVE( SELE, LABE = "cw3" )
CURVE( SELE, LABE = "cw15" )
(   VE( SELE, LABE = "cwz3" )
CURVE( SELE, LABE = "csu113" )
SURFACE( ADD, WIRE, EDG1 - 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s21" )
/
CURVE( SELE, LABE = "cc4" )
CURVE( SELE, LABE = "cw16" )
CURVE( SELE, LABE = "ccz4" )
CURVE( SELE, LABE = "cw15" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s22" )
/
CURVE( SELE, LABE = "cw8" )
CURVE( SELE, LABE = "cw16" )
CURVE( SELE, LABE = "cwz8" )
CURVE( SELE, LABE = "csu111" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s23" )
/
///////
/
CURVE( SELE, LABE = "cc4" )
CURVE( SELE, LABE = "ccz4" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw3" )
CURVE( SELE, LABE = "cwz3" )
CURVE( SELE, LABE = "cw8" )
(   VE( SELE, LABE = "cwz8" )
M  GE( ADD, RATI = 1.05, INTE = 18 )
/
CURVE( SELE, LABE = "cw15" )
CURVE( SELE, LABE = "cw16" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE - 10 )
/
///////
/
CURVE( SELE, LABE = "cw3" )
CURVE( SELE, LABE = "cc4" )
CURVE( SELE, LABE = "cw8" )
CURVE( SELE, LABE = "csu112" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml2" )
/
CURVE( SELE, LABE = "cwz3" )
CURVE( SELE, LABE = "ccz4" )
CURVE( SELE, LABE = "cwz8" )
CURVE( SELE, LABE = "csu114" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "mlz2" )
/
CURVE( SELE, LABE = "cw3" )
CURVE( SELE, LABE = "cw15" )
CURVE( SELE, LABE = "cwz3" )
CURVE( SELE, LABE = "csu113" )
M  OOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml21" )
.
CURVE( SELE, LABE = "cc4" )
CURVE( SELE, LABE = "cw16" )
CURVE( SELE, LABE = "ccz4" )
```

```
CURVE( SELE, LABE = "cw15" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml22" )
/
CURVE( SELE, LABE = "cw8" )
CURVE( SELE, LABE = "cw16" )
(   VE( SELE, LABE = "cwz8" )
CURVE( SELE, LABE = "csu111" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml23" )
/
//////
/
SURFACE( SELE, LABE = "s2" )
MLOOP( SELE, LABE = "ml2" )
MFACE( ADD, LABE = "mf2" )
/
SURFACE( SELE, LABE = "sz2" )
MLOOP( SELE, LABE = "mlz2" )
MFACE( ADD, LABE = "mfz2" )
/
SURFACE( SELE, LABE = "s21" )
MLOOP( SELE, LABE = "ml21" )
MFACE( ADD, LABE = "mf21" )
/
SURFACE( SELE, LABE = "s22" )
MLOOP( SELE, LABE = "ml22" )
MFACE( ADD, LABE = "mf22" )
/
SURFACE( SELE, LABE = "s23" )
MLOOP( SELE, LABE = "ml23" )
MFACE( ADD, LABE = "mf23" )
/
//////
/
MFACE( SELE, LABE = "mf2" )
MFACE( SELE, LABE = "mfz2" )
MFACE( SELE, LABE = "mf21" )
MFACE( SELE, LABE = "mf22" )
MFACE( SELE, LABE = "mf23" )
MFACE( SELE, LABE = "mfsu114" )
MSHELL( ADD, VISI, LABE = "mshell2" )
/
///////
/
MSHELL( SELE, LABE = "mshell2" )
MSOLID( ADD, MAP, LABE = "msolid2" )
/
/////
/
POINT( SELE, LABE = "w4" )
POINT( SELE, LABE = "w5" )
CURVE( ADD, LINE, LABE = "cw4" )
/
POINT( SELE, LABE = "w11" )
POINT( SELE, LABE = "w10" )
CURVE( ADD, LINE, LABE = "cw7" )
/
(   NT( SELE, LABE = "zw4" )
POINT( SELE, LABE = "zw5" )
CURVE( ADD, LINE, LABE = "cwz4" )
/
```

```
POINT( SELE, LABE = "zw11" )
POINT( SELE, LABE = "zw10" )
CURVE( ADD, LINE, LABE = "cwz7" )
/
POINT( SELE, LABE = "w7" )
POINT( SELE, LABE = "zw7" )
CURVE( ADD, LINE, LABE = "cw17" )
/
POINT( SELE, LABE = "w8" )
POINT( SELE, LABE = "zw8" )
CURVE( ADD, LINE, LABE = "cw18" )
/
POINT( SELE, LABE = "w5" )
POINT( SELE, LABE = "w6" )
POINT( SELE, LABE = "w7" )
CURVE( ADD, ARC, LABE = "cw5" )
/
POINT( SELE, LABE = "zw5" )
POINT( SELE, LABE = "zw6" )
POINT( SELE, LABE = "zw7" )
CURVE( ADD, ARC, LABE = "cwz5" )
/
POINT( SELE, LABE = "w10" )
POINT( SELE, LABE = "w9" )
POINT( SELE, LABE = "w8" )
CURVE( ADD, ARC, LABE = "cw6" )
/
POINT( SELE, LABE = "zw10" )
POINT( SELE, LABE = "zw9" )
POINT( SELE, LABE = "zw8" )
CURVE( ADD, ARC, LABE = "cwz6" )
/
POINT( SELE, LABE = "w7" )
POINT( SELE, LABE = "w8" )
CURVE( ADD, LINE, LABE = "co1" )
/
POINT( SELE, LABE = "zw7" )
POINT( SELE, LABE = "zw8" )
CURVE( ADD, LINE, LABE = "coz1" )
/
////////
/
CURVE( SELE, LABE = "cw4" )
CURVE( SELE, LABE = "cw5" )
CURVE( SELE, LABE = "co1" )
CURVE( SELE, LABE = "cw6" )
CURVE( SELE, LABE = "cw7" )
CURVE( SELE, LABE = "cc4" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "s3" )
/
CURVE( SELE, LABE = "cwz4" )
CURVE( SELE, LABE = "cwz5" )
CURVE( SELE, LABE = "coz1" )
CURVE( SELE, LABE = "cwz6" )
CURVE( SELE, LABE = "cwz7" )
CURVE( SELE, LABE = "ccz4" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "sz3" )
/
CURVE( SELE, LABE = "cw4" )
CURVE( SELE, LABE = "cw5" )
```

```
CURVE( SELE, LABE = "cw17" )
CURVE( SELE, LABE = "cwz5" )
CURVE( SELE, LABE = "cwz4" )
CURVE( SELE, LABE = "cw15" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "s31" )
/
CURVE( SELE, LABE = "co1" )
CURVE( SELE, LABE = "cw18" )
CURVE( SELE, LABE = "coz1" )
CURVE( SELE, LABE = "cw17" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s32" )
/
CURVE( SELE, LABE = "cw7" )
CURVE( SELE, LABE = "cw6" )
CURVE( SELE, LABE = "cw18" )
CURVE( SELE, LABE = "cwz6" )
CURVE( SELE, LABE = "cwz7" )
CURVE( SELE, LABE = "cw16" )
SURFACE( ADD, WIRE, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "s33" )
/
///////
/
CURVE( SELE, LABE = "cw4" )
CURVE( SELE, LABE = "cw7" )
CURVE( SELE, LABE = "cwz4" )
CURVE( SELE, LABE = "cwz7" )
MEDGE( ADD, INTE = 6 )
/
CURVE( SELE, LABE = "cw5" )
CURVE( SELE, LABE = "cw6" )
CURVE( SELE, LABE = "cwz5" )
CURVE( SELE, LABE = "cwz6" )
MEDGE( ADD, RATI = 1.1, INTE = 10 )
/
CURVE( SELE, LABE = "co1" )
CURVE( SELE, LABE = "coz1" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "cw17" )
CURVE( SELE, LABE = "cw18" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
////////
/
CURVE( SELE, LABE = "cw4" )
CURVE( SELE, LABE = "cw5" )
CURVE( SELE, LABE = "co1" )
CURVE( SELE, LABE = "cw6" )
CURVE( SELE, LABE = "cw7" )
CURVE( SELE, LABE = "cc4" )
MLOOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "ml3" )
/
CURVE( SELE, LABE = "cwz4" )
CURVE( SELE, LABE = "cwz5" )
CURVE( SELE, LABE = "coz1" )
CURVE( SELE, LABE = "cwz6" )
CURVE( SELE, LABE = "cwz7" )
CURVE( SELE, LABE = "ccz4" )
MLOOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "mlz3"
/
```

```
CURVE( SELE, LABE = "cw4" )
CURVE( SELE, LABE = "cw5" )
CURVE( SELE, LABE = "cw17" )
CURVE( SELE, LABE = "cwz5" )
CURVE( SELE, LABE = "cwz4" )
(   VE( SELE, LA   = "cw15" )
MLOOP( ADD, MAP, VISI, EDG1 - 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "ml31" )
/
CURVE( SELE, LABE = "co1" )
CURVE( SELE, LABE = "cw18" )
CURVE( SELE, LABE = "coz1" )
CURVE( SELE, LABE = "cw17" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml32" )
/
CURVE( SELE, LABE = "cw7" )
CURVE( SELE, LABE = "cw6" )
CURVE( SELE, LABE = "cw18" )
CURVE( SELE, LABE = "cwz6" )
CURVE( SELE, LABE = "cwz7" )
CURVE( SELE, LABE = "cw16" )
MLOOP( ADD, MAP, VISI, EDG1 = 2, EDG2 = 1, EDG3 = 2, EDG4 = 1, LABE = "ml33" )
/
///////
/
SURFACE( SELE, LABE = "s3" )
MLOOP( SELE, LABE = "ml3" )
MFACE( ADD, LABE = "mf3" )
/
SURFACE( SELE, LABE = "sz3" )
MLOOP( SELE, LABE = "mlz3" )
!   CE( ADD, LABE = "mfz3" )
/
SURFACE( SELE, LABE = "s31" )
MLOOP( SELE, LABE = "ml31" )
MFACE( ADD, LABE = "mf31" )
/
SURFACE( SELE, LABE = "s32" )
MLOOP( SELE, LABE = "ml32" )
MFACE( ADD, LABE = "mf32" )
/
SURFACE( SELE, LABE = "s33" )
MLOOP( SELE, LABE = "ml33" )
MFACE( ADD, LABE = "mf33" )
/
MFACE( SELE, LABE = "mf3" )
MFACE( SELE, LABE = "mfz3" )
MFACE( SELE, LABE = "mf31" )
MFACE( SELE, LABE = "mf32" )
MFACE( SELE, LABE = "mf33" )
MFACE( SELE, LABE = "mf22" )
MSHELL( ADD, VISI, LABE = "mshell3" )
/
///////
/
MSHELL( SELE, LABE = "mshell3" )
MSOLID( ADD, MAP, LABE = "msolid3" )
/
////// Fourth solid //////////
/
POINT( SELE, LABE = "w13" )
```

```
POINT( SELE, LABE = "w14" )
POINT( SELE, LABE = "w15" )
CURVE( ADD, ARC, LABE = "cw10" )
/
POINT( SELE, LABE = "zw13" )
POINT( SELE, LABE = "zw14"
POINT( SELE, LABE = "zw15" )
CURVE( ADD, ARC, LABE = "cwz10" )
/
POINT( SELE, LABE = "i2" )
POINT( SELE, LABE = "w15" )
CURVE( ADD, LINE, LABE = "cc2" )
/
POINT( SELE, LABE = "zi2" )
POINT( SELE, LABE = "zw15" )
CURVE( ADD, LINE, LABE = "ccz2" )
/
POINT( SELE, LABE = "w1" )
POINT( SELE, LABE = "i2" )
CURVE( ADD, LINE, LABE = "ci1" )
/
POINT( SELE, LABE = "zw1" )
POINT( SELE, LABE = "zi2" )
CURVE( ADD, LINE, LABE = "ciz1" )
/
POINT( SELE, LABE = "w15" )
POINT( SELE, LABE = "zw15" )
CURVE( ADD, LINE, LABE = "cw19" )
/
POINT( SELE, LABE - "i2" )
POINT( SELE, LABE = "zi2" )
CURVE( ADD, LINE, LABE = "cw110" )
/
///////
/
CURVE( SELE, LABE = "cc1" )
CURVE( SELE, LABE = "cw10" )
CURVE( SELE, LABE = "cc2" )
CURVE( SELE, LABE = "ci1" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s4" )
/
CURVE( SELE, LABE = "ccz1" )
CURVE( SELE, LABE = "cwz10" )
CURVE( SELE, LABE = "ccz2" )
CURVE( SELE, LABE = "ciz1" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "sz4" )
/
CURVE( SELE, LABE = "cw10" )
CURVE( SELE, LABE = "cw19" )
CURVE( SELE, LABE = "cwz10" )
CURVE( SELE, LABE = "cw14" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s42" )
/
CURVE( SELE, LABE = "cc2" )
CURVE( SELE, LABE = "cw110" )
CURVE( SELE, LABE = "ccz2" )
CURVE( SELE, LABE = "cw19" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s43" )
/
CURVE( SELE, LABE = "ci1" )
```

```
CURVE( SELE, LABE = "cwl10" )
CURVE( SELE, LABE = "cizi" )
CURVE( SELE, LABE = "cwl1" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s44" )
/
(   '//
/
CURVE( SELE, LABE = "cc2" )
CURVE( SELE, LABE = "ccz2" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
CURVE( SELE, LABE = "ci1" )
CURVE( SELE, LABE = "cw10" )
CURVE( SELE, LABE = "cizi" )
CURVE( SELE, LABE = "cwz10" )
MEDGE( ADD, INTE = 10 )
/
CURVE( SELE, LABE = "cwl9" )
CURVE( SELE, LABE = "cwl10" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
/////
/
CURVE( SELE, LABE = "cc1" )
CURVE( SELE, LABE = "cw10" )
CURVE( SELE, LABE = "cc2" )
CURVE( SELE, LABE = "ci1" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml4" )
/
CURVE( SELE, LABE = "ccz1" )
(   'E( SELE, LABE = "cwz10" )
Cu.VE( SELE, LABE - "ccz2" )
CURVE( SELE, LABE = "cizi" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "mlz4" )
/
CURVE( SELE, LABE = "cw10" )
CURVE( SELE, LABE = "cwl9" )
CURVE( SELE, LABE = "cwz10" )
CURVE( SELE, LABE = "cwl4" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml42" )
/
CURVE( SELE, LABE = "cc2" )
CURVE( SELE, LABE = "cwl10" )
CURVE( SELE, LABE = "ccz2" )
CURVE( SELE, LABE = "cwl9" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml43" )
/
CURVE( SELE, LABE = "ci1" )
CURVE( SELE, LABE = "cwl10" )
CURVE( SELE, LABE = "cizi" )
CURVE( SELE, LABE = "cwl1" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml44" )
//
///////
/
SURFACE( SELE, LABE = "s4" )
(   OP( SELE, LABE = "ml4" )
MFACE( ADD, LABE = "mf4" )
/
SURFACE( SELE, LABE = "sz4" )
```

```
MLOOP( SELE, LABE = "mlz4" )
MFACE( ADD, LABE = "mfz4" )
/
SURFACE( SELE, LABE = "s42" )
MLOOP( SELE, LABE = "ml42" )
(   CE( ADD, LABE = "mf42" )
/
SURFACE( SELE, LABE = "s43" )
MLOOP( SELE, LABE = "ml43" )
MFACE( ADD, LABE = "mf43" )
/
SURFACE( SELE, LABE = "s44" )
MLOOP( SELE, LABE = "ml44" )
MFACE( ADD, LABE = "mf44" )
/
///////
/
MFACE( SELE, LABE = "mf4" )
MFACE( SELE, LABE = "mfz4" )
MFACE( SELE, LABE = "mf14" )
MFACE( SELE, LABE = "mf42" )
MFACE( SELE, LABE = "mf43" )
MFACE( SELE, LABE = "mf44" )
MSHELL( ADD, VISI, LABE = "mshell4" )
/
///////
/
MSHELL( SELE, LABE = "mshell4" )
MSOLID( ADD, MAP, LABE = "msolid4" )
/
/   /// Fifth solid /////////
/
POINT( SELE, LABE = "w16" )
POINT( SELE, LABE = "i1" )
CURVE( ADD, LINE, LABE = "co2" )
/
POINT( SELE, LABE = "zw16" )
POINT( SELE, LABE = "zi1" )
CURVE( ADD, LINE, LABE = "coz2" )
/
POINT( ADD, NOSH, LABE = "i301", Z = -1.5748, COOR, X = 0, Y = 48.75161568 )
POINT( SELE, LABE = "i2" )
POINT( SELE, LABE = "i301" )
POINT( SELE, LABE = "i1" )
CURVE( ADD, ARC, LABE = "ci2" )
/
POINT( ADD, NOSH, LABE = "zi301", Z = 1.5748, COOR, X = 0, Y = 48.75161568 )
POINT( SELE, LABE = "zi2" )
POINT( SELE, LABE = "zi301" )
POINT( SELE, LABE = "zi1" )
CURVE( ADD, ARC, LABE = "ciz2" )
/
POINT( ADD, NOSH, LABE = "w302", Z = -1.5748, COOR, X = 5.057456634,
Y = 52.94364912 )
POINT( SELE, LABE = "w15" )
POINT( SELE, LABE = "w302" )
(   NT( SELE, LABE = "w16" )
CURVE( ADD, ARC, LABE = "cw11" )
/
POINT( ADD, NOSH, LABE = "zw302", Z = 1.5748, COOR, X = 5.057456634,
```

```
Y = 52.94364912 )
POINT( SELE, LABE = "zw15" )
POINT( SELE, LABE = "zw302" )
POINT( SELE, LABE = "zw16" )
CURVE( ADD, ARC, LABE = "cwz11" )
/
POINT( SELE, LABE = "i1" )
POINT( SELE, LABE = "zi1" )
CURVE( ADD, LINE, LABE = "cw111" )
/
POINT( SELE, LABE = "w16" )
POINT( SELE, LABE = "zw16" )
CURVE( ADD, LINE, LABE = "cw112" )
/
//////
/
CURVE( SELE, LABE = "cw11" )
CURVE( SELE, LABE = "co2" )
CURVE( SELE, LABE = "ci2" )
CURVE( SELE, LABE = "cc2" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s5" )
/
CURVE( SELE, LABE = "cwz11" )
CURVE( SELE, LABE = "coz2" )
CURVE( SELE, LABE = "ciz2" )
CURVE( SELE, LABE = "ccz2" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "sz5" )
/
CURVE( SELE, LABE = "cw11" )
CURVE( SELE, LABE = "cw112" )
CURVE( SELE, LABE = "cwz11" )
CURVE( SELE, LABE = "cw19" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s51" )
/
CURVE( SELE, LABE - "co2" )
CURVE( SELE, LABE = "cw111" )
CURVE( SELE, LABE = "coz2" )
CURVE( SELE, LABE = "cw112" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s52" )
/
CURVE( SELE, LABE = "ci2" )
CURVE( SELE, LABE = "cw111" )
CURVE( SELE, LABE = "ciz2" )
CURVE( SELE, LABE = "cw110" )
SURFACE( ADD, WIRE, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "s53" )
//
///////
/
CURVE( SELE, LABE = "co2" )
CURVE( SELE, LABE = "coz2" )
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
//
CURVE( SELE, LABE = "cw11" )
CURVE( SELE, LABE = "ci2" )
CURVE( SELE, LABE = "cwz11" )
CURVE( SELE, LABE = "ciz2" )
MEDGE( ADD, INTE = 12 )
/
CURVE( SELE, LABE = "cw111" )
CURVE( SELE, LABE = "cw112" )
```

```
MEDGE( ADD, LSTF, RATI = 8, 2RAT = 8, INTE = 10 )
/
///////
/
CURVE( SELE, LABE = "cw11" )
CURVE( SELE, LABE = "co2" )
CURVE( SELE, LABE = "ci2" )
CURVE( SELE, LABE = "cc2" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml5" )
/
CURVE( SELE, LABE = "cwz11" )
CURVE( SELE, LABE = "coz2" )
CURVE( SELE, LABE = "ciz2" )
CURVE( SELE, LABE = "ccz2" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 - 1, EDG4 = 1, LABE = "mlz5" )
/
CURVE( SELE, LABE = "cw11" )
CURVE( SELE, LABE = "cw112" )
CURVE( SELE, LABE = "cwz11" )
CURVE( SELE, LABE = "cw19" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml51" )
/
CURVE( SELE, LABE = "co2" )
CURVE( SELE, LABE = "cw111" )
CURVE( SELE, LABE = "coz2" )
CURVE( SELE, LABE = "cw112" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 = 1, LABE = "ml52" )
/
CURVE( SELE, LABE = "ci2" )
CURVE( SELE, LABE = "cw110" )
CURVE( SELE, LABE = "ciz2" )
CURVE( SELE, LABE = "cw111" )
MLOOP( ADD, MAP, VISI, EDG1 = 1, EDG2 = 1, EDG3 = 1, EDG4 - 1, LABE = "ml53" )
//
///////
/
SURFACE( SELE, LABE = "s5" )
MLOOP( SELE, LABE = "ml5" )
MFACE( ADD, LABE - "mf5" )
/
SURFACE( SELE, LABE = "sz5" )
MLOOP( SELE, LABE = "mlz5" )
MFACE( ADD, LABE = "mfz5" )
/
SURFACE( SELE, LABE = "s51" )
MLOOP( SELE, LABE = "ml51" )
MFACE( ADD, LABE = "mf51" )
/
SURFACE( SELE, LABE = "s52" )
MLOOP( SELE, LABE = "ml52" )
MFACE( ADD, LABE = "mf52" )
/
SURFACE( SELE, LABE = "s53" )
MLOOP( SELE, LABE = "ml53" )
MFACE( ADD, LABE = "mf53" )
/
/ /////
/
MFACE( SELE, LABE = "mf5" )
MFACE( SELE, LABE = "mfz5" )
```

```
MFACE( SELE, LABE = "mf51" )
MFACE( SELE, LABE = "mf52" )
MFACE( SELE, LABE = "mf53" )
MFACE( SELE, LABE = "mf43" )
MSHELL( ADD, VISI, LABE = "mshell5" )
(
//////
/
MSHELL( SELE, LABE = "mshell5" )
MSOLID( ADD, MAP, LABE = "msolid5" )
/
/////// set up entity and mesh ////////////
/
ELEMENT( SETD, BRIC, NODE = 8 )
MSOLID( SELE, LABE = "msolid1" )
MSOLID( SELE, LABE = "msolidsu1" )
MSOLID( SELE, LABE = "msolidsu2" )
MSOLID( SELE, LABE = "msolidsu3" )
MSOLID( SELE, LABE = "msolidsu4" )
MSOLID( SELE, LABE = "msolidsu5" )
MSOLID( SELE, LABE = "msolidsu6" )
MSOLID( SELE, LABE = "msolidsu7" )
MSOLID( SELE, LABE = "msolidsu8" )
MSOLID( SELE, LABE = "msolidsu9" )
MSOLID( SELE, LABE = "msolidsu10" )
MSOLID( SELE, LABE = "msolidsu11" )
MSOLID( SELE, LABE = "msolid2" )
MSOLID( SELE, LABE = "msolid3" )
MSOLID( SELE, LABE = "msolid4" )
MSOLID( SELE, LABE = "msolid5" )
  LID( MESH, MAP, ENTI = "fluid" )
/
////////
/
ELEMENT( SETD, QUAD, NODE = 4 )
MFACE( SELE, LABE = "mf53" )
MFACE( MESH, MAP, ENTI = "inlet" )
/
ELEMENT( SETD, QUAD, NODE - 4 )
MFACE( SELE, LABE = "mf32" )
MFACE( MESH, MAP, ENTI = "outlet" )
/
ELEMENT( SETD, QUAD, NODE = 4 )
MFACE( SELE, LABE = "mf44" )
MFACE( MESH, MAP, ENTI = "ref" )
/
ELEMENT( SETD, QUAD, NODE = 4 )
MFACE( SELE, LABE = "mf52" )
MFACE( MESH, MAP, ENTI = "per" )
/
ELEMENT( SETD, QUAD, NODE = 4 )
MFACE( SELE, LABE = "mf1" )
MFACE( SELE, LABE = "mfz1" )
MFACE( SELE, LABE = "mf11" )
MFACE( SELE, LABE = "mf13" )
MFACE( SELE, LABE = "mf2" )
M  CE( SELE, LABE - "mfz2" )
MFACE( SELE, LABE = "mf21" )
MFACE( SELE, LABE = "mf23" )
MFACE( SELE, LABE = "mfsu11" )
```

```
MFACE( SELE, LABE = "mfsu12" )
MFACE( SELE, LABE = "mfsu13" )
MFACE( SELE, LABE = "mfsu21" )
MFACE( SELE, LABE = "mfsu22" )
MFACE( SELE, LABE = "mfsu23" )
MFACE( SELE, LABE = "mfsu25" )
MFACE( SELE, LABE = "mfsu31" )
MFACE( SELE, LABE = "mfsu32" )
MFACE( SELE, LABE = "mfsu33" )
MFACE( SELE, LABE = "mfsu41" )
MFACE( SELE, LABE = "mfsu42" )
MFACE( SELE, LABE = "mfsu43" )
MFACE( SELE, LABE = "mfsu45" )
MFACE( SELE, LABE = "mfsu51" )
MFACE( SELE, LABE = "mfsu52" )
MFACE( SELE, LABE = "mfsu53" )
MFACE( SELE, LABE = "mfsu61" )
MFACE( SELE, LABE = "mfsu62" )
MFACE( SELE, LABE = "mfsu63" )
MFACE( SELE, LABE = "mfsu65" )
MFACE( SELE, LABE = "mfsu71" )
MFACE( SELE, LABE = "mfsu72" )
MFACE( SELE, LABE = "mfsu73" )
MFACE( SELE, LABE = "mfsu81" )
MFACE( SELE, LABE = "mfsu82" )
MFACE( SELE, LABE = "mfsu83" )
MFACE( SELE, LABE = "mfsu85" )
MFACE( SELE, LABE = "mfsu91" )
MFACE( SELE, LABE = "mfsu92" )
MFACE( SELE, LABE = "mfsu93" )
MFACE( SELE, LABE = "mfsu101" )
MFACE( SELE, LABE = "mfsu102" )
MFACE( SELE, LABE = "mfsu103" )
MFACE( SELE, LABE = "mfsu105" )
MFACE( SELE, LABE = "mfsu111" )
MFACE( SELE, LABE = "mfsu112" )
MFACE( SELE, LABE = "mfsu113" )
MFACE( SELE, LABE = "mf3" )
MFACE( SELE, LABE = "mfz3" )
MFACE( SELE, LABE = "mf31" )
MFACE( SELE, LABE = "mf33" )
MFACE( SELE, LABE = "mf4" )
MFACE( SELE, LABE = "mfz4" )
MFACE( SELE, LABE = "mf42" )
MFACE( SELE, LABE = "mf5" )
MFACE( SELE, LABE = "mfz5" )
MFACE( SELE, LABE = "mf51" )
MFACE( MESH, MAP, ENTI = "wall" )
/
ELEMENT( SETD, QUAD, NODE = 4 )
MFACE( SELE, LABE = "mfsu15" )
MFACE( SELE, LABE = "mfsu35" )
MFACE( SELE, LABE = "mfsu55" )
MFACE( SELE, LABE = "mfsu75" )
MFACE( SELE, LABE = "mfsu95" )
MFACE( SELE, LABE = "mfsu115" )
MFACE( MESH, MAP, ENTI = "slit" )
/
END( )
////
```

```
////////////////// boundary group //////////
/////
FI-BC(  )
WINDOW(CHANGE= 1, MATRIX )
   -0.707107   -0.408248    0.577350    0.000000
{   0.707107   -0.408248    0.577350    0.000000
    0.000000    0.816497    0.577350    0.000000
    0.000000    0.000000    0.000000    1.000000
    -5.27295    48.91325   -48.16096   -7.52132    15.97957    62.76707
WINDOW( CHAN = 1, MATR )
-0.707107, -0.408248, 0.57735,     0
0.707107, -0.408248, 0.57735,     0
    0, 0.816497, 0.57735,     0
    0,      0,      0,      1
-5.27295, 48.91325, -48.16096, -7.52132, 15.97957, 62.76707
/
////////// setup entity ////////////////
/
BGADD( SELE, EDGE, ID = 3980 )
BGADD( ADD, EDGE, ENTI = "edger" )
BGADD( SELE, EDGE, ID = 4071 )
BGADD( ADD, EDGE, ENTI - "edgep" )
/
END(  )
/
/// create a FIINP file for looking for corner nodes
/
CREATE( FIIN )
/
////////////////// input boundary inittial condition and perperties.
/
F..REP(  )
/
/ simulation control
/
PROBLEM( 3-D, NONL, TURB )
/EXECUTION(NEWJOB)
EXECUTION( REST )
SOLUTION( SEGR = 245, ACCF = 0.5, VELC = 0.0002 )
/STRATEGY(SEGREGATED)
/3(u,v)=0.2:1.e-3
/5{5(p,2(u,v=0.2):1.e-2)=0.1:1.e-4}:1.e-4
OPTIONS( UPWI )
PRESSURE( MIXE = 1e-15, CONT )
TURBCONSTANTS(  )
    0,      0,      0,      0,      0,      1
POSTPROCESS(  )
/
/mesh data
/
/RENUMBER(off)
/
/ material properties
/
VISCOSITY( K.E., CONS = 1.626373e-05 )
DENSITY( CONS = 1 )
/
/ initial and boundary condition
/
ICNODE( KINE, CONS = 0.005, ALL )
```

```
ICNODE( DISS, CONS = 0.001059, ALL )
/
///// per and ref are periodic boundary, but without the corner point.
/
BCPERIODIC( UT1, UN3, ENTI, REFE = "ref", PERI = "per", EXCL, R1NO = 1,
(   ) = 883, P1NO = 937, P2NO = 939 )
/
//// inlet boundary condition, but the corner nodes need redefine.
/
BCNODE( KINE, CONS = 0.005, ENTI = "inlet", INCL )
BCNODE( DISS, CONS = 0.001059, ENTI = "inlet", INCL )
BCNODE( UT1, CONS = -0.9999452, ENTI = "inlet", EXCL )
BCNODE( UT2, CONS = 0, ENTI = "inlet", EXCL )
BCNODE( UN3, CONS = -0.0104722, ENTI = "inlet", EXCL )
/
//// suction boundary contion
/
BCNODE( UX, CONS = 0.00779, ENTI = "slit" )
BCNODE( UY, CONS = 0.005459, ENTI = "slit" )
BCNODE( UZ, CONS = 0, ENTI = "slit" )
/
/ in order to get normal right, BCSYSTEM and BCNODE(COORDINATE)
/ have to be used, then you have define corner node specifically.
/
BCSYSTEM( SET = 1, EDGE, 2TAN )
    0,     0,     0,     0,     0,     0,     0,     0,     1
BCNODE( COOR, ENTI = "inlet" )
/
BCNODE( UN3, CONS = -0.9999452, ENTI = "edger" )
BCNODE( UT1, CONS = 0.01047422, ENTI = "edger" )
   ODE( UT2, CONS = 0, ENTI = "edger" )
/
BCNODE( UN3, CONS = 0.9999452, ENTI = "edgep" )
BCNODE( UT1, CONS = -0.0104722, ENTI = "edgep" )
BCNODE( UT2, CONS = 0, ENTI = "edgep" )
/
BCNODE( VELO, ZERO, ENTI = "wall" )
/
/ entity properties
/
ENTITY( FLUI, NAME = "fluid" )
/
ENTITY( PLOT, NAME = "outlet" )
/
ENTITY( SLIP, NAME = "per" )
ENTITY( SLIP, NAME = "ref" )
/
ENTITY( SLIP, NAME = "inlet" )
/
ENTITY( PLOT, NAME = "slit" )
/
ENTITY( WALL, NAME = "wall" )
/
ENTITY( PLOT, NAME = "edger" )
ENTITY( PLOT, NAME = "edgep" )
/
    ( )
/
CREATE( FISO )
RUN (FISO, BACK, FISOLVME = 8000000 )
```